UNCLASSIFIED

INVESTIGATION TOWARD OBTAINING SIGNIFICANTLY HIGHER MECHANICAL PROPERTIES OF AS-WELDED JOINTS IN HIGH-STRENGTH, HEAT TREATABLE ALUMINUM ALLOYS

By

F. R. Collins

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Signed: Fred R Collins
Asst. Chief
Process Metallurgy Division

Date 9-20-63

Approved: [signature]
Chief, Process Metallurgy Division

Date 9/20/63

Aluminum Company of America
Alcoa Research Laboratories
New Kensington, Pennsylvania

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By

F. R. COLLINS

ABSTRACT

This report describes the second phase of an investigation to improve welds in high strength aluminum alloys such as 7075 and 7178.[2]

Direct current, straight polarity, helium shielded tungsten arc automatic welding was preferred for most consistent results, although highest individual weld strengths were achieved with carefully controlled consumable electrode short arc technique. High travel speeds, with TIG welding, decreased weld strength because of small hot-short cracks.

Cold working of welds before aging often caused cracks and had no beneficial effect on strength.

Locally heat treating welds with a low power arc before aging increased ductility in both tensile and bulge tests. Strength was about equivalent to non-heated welds. Base metal properties determined after short time exposure to high temperatures were used to predict joint designs for local heat treatments. Additional work with low specific energy heat sources such as a flame is recommended.

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1. Phase Report No. 1, DA Project 593-32-005, Ordnance Project TB4-005; Alcoa Report No. 2-61-44, "Investigation Toward Obtaining Significantly Higher Mechanical Properties of As-Welded Joints in High-Strength, Heat Treatable Aluminum Alloys."

   See also, Collins, F.R., "Improved Strengths in Welded High Strength, Heat Treatable Aluminum Alloys, Welding Journal 41, (8) Research Supplement pp 3375-3455 (1962).

Two filler metals, 6 Zn-3 Mg-.2 Ti (M743) and 8 Zn-2.5 Mg-.5 Mn-.8 Cu had low sensitivity to hot short cracking and gave stronger welds than X5080 for assemblies that can be post weld solution heat treated. No advantage was found for fillers of high purity with respect to Fe and Si.

Microprobe analyses of high purity 7075 welded with 4043 revealed penetration of filler metal into partially melted base metal. The transport mechanism has not been established, but it is clear that filler composition can affect the characteristics of partially melted base metal adjacent the weld.

Residual and clamping stresses, in the absence of sufficient weld ductility to permit mechanical stress relief, caused failures in the bulge test at low nominal stress. Stretching prior to post weld aging improved correlation between tensile and bulge tests. This was most effective for -W temper base metal, which yields lower ultimate weld strength on post weld aging than -T6 temper metal.

Reducing Fe and Si to about 0.07 per cent in 7075-type base metals improved strength and ductility in welds solution heat treated and aged. A combination of high purity 7075-type base metal with copper reduced to 0.8 per cent and the 8 Zn filler gave best results. As-welded or post-weld aged joint strengths were not improved over standard compositions.

Base metals 7178-T6 and 7075-T6 welded with X5080 and post-weld aged had satisfactory resistance to stress corrosion cracking at stress levels up to about 30 KSI. General resistance to corrosion was improved by post-weld aging, but protective systems are recommended for all but very mild exposures.

INTRODUCTION

In Phase 1 of this investigation it was reported that highest strengths in welded aluminum structures without reheat treating were achieved by welding alloys 7075 and 7178 with filler metal X5080, then post weld aging.

Strength was greatly influenced by welding technique. Highest properties and best reliability were achieved by automatic welding using the direct current, straight polarity helium shielded tungsten arc process. Full-section weld strength was limited by the properties of the partially melted base metal adjacent to the weld. When the weld reinforcement was removed, failure occurred in the center of the weld bead.

To achieve higher properties and greater reliability, particularly in complex structures, improvements in these three general areas were shown to be needed: (1) stronger filler metals of low sensitivity to hot-short cracking, (2) base metal compositions less damaged by partial melting in the weld area, and (3) welding techniques and procedures that reduce damage to the base metal by minimizing the heat affected zones.

This report describes investigations in these and related areas.

MATERIALS AND EQUIPMENT

The aluminum base metals investigated were the standard 7075 and 7178 compositions and experimental modifications of this alloy type. Filler metals included 5556, 5554, X5080, and experimental Al-Zn-Mg alloys. The nominal compositions of these and other alloys discussed later in this report are listed in Table I.

Equipment for gas tungsten-arc welding was: (1) Airco Model 3ADB245CHABP 300-amp, AC-DC heliwelder, (2) Airco Model HMH-E heliweld automatic head, (3) Oxweld Type CM-37 machine carriage, and (4) 36-in. welding table with grooved copper backup. Gas metal-arc equipment was: (1) Miller model CP3VS DC welder, (2) Linde model SVI-500 variable slope and inductance DC welder, (3) Aircomatic filler wire feeder model AHF-C and model AHF-B control, (4) Aircomatic "pull" gun model AHF-35A, (5) Airco No. 20 Radiagraph, and (6) 36-in. welding table with grooved copper backup.

Esterline-Angus model AW meters were used to record volts and amperes.

Shielding gases were Linde high purity dry (99.995%) argon and Airco grade A helium.

TEST METHODS

Nondestructive Tests

Welds were inspected visually for smooth flow and complete penetration. Each weld was radiographed using a suitable penetrameter and the films compared with known standards. Usually welds were not further tested that did not exhibit soundness at least as good as Class 2 ABMA-PD-R-27.

Tensile Tests

Standard sheet-type tensile specimens were used for all gages of welded sheet for both full section and flush bead samples.

Bulge Tests

The 8-in. nominal diameter hydrostatic bulge tester previously described[2] was used in these tests.

Corrosion Tests

Susceptibility to stress corrosion cracking was determined by stressing pairs of specimens over a small H-beam to 75 per cent of the tensile or yield strength of the joint and exposing them to alternate immersion, 10 minutes in, 50 minutes out in 3-1/2 per cent sodium chloride solution. General corrosion was evaluated by exposing unstressed specimens to the same environment.

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2. The Hydraulic Bulge Test for Welded Aluminum Sheet, by I.B. Robinson, F.R. Collins, J.D. Dowd; Welding Journal, 12/61

RESULTS

Welding Procedures

Frankford Arsenal achieved high strength in 2014 and 2024 aluminum alloys by MIG welding on a backup chilled by brine or liquid nitrogen.[3] Tensile strengths approximately 90 per cent that of the base metal in heat treated tempers were achieved by post weld aging.

In attempting to achieve similar response in 1/8-in. 7075 and 7178 alloys without artificially cooled backup, direct current, straight polarity, tungsten arc welds were made at travel speeds of 20, 40, 60, and 80 inches per minute. To avoid longitudinal hot short cracking and undercutting, however, it was necessary to increase filler metal speed by a greater amount than travel speed. This provided the additional liquid metal needed to heal "incipient" cracks formed during more rapid weld solidification and to maintain proper bead configuration.

Welds at high travel speeds showed no visual defects, although beads had a more rippled appearance. Radiographic examination and dye penetrant tests, however, disclosed small transverse cracks. These cracks had significant depth since they were still found after the weld beads were shaved flush. Figure 1, a photograph of a typical weld made at high speed in 1/8-in. 7178, shows the transverse cracks outlined by dye penetrant and white developer.

Transverse cracking occurred in welded 7178 and 7075 with X5080, 5556, and 5356 filler metals. Tensile and bulge tests were made on panels welded with X5080 filler, however, to determine the influence of these cracks on weld properties. The results are

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3. Schillinger, D.E., Betz, I.G., Hussey, F.W., Markus, H., Welding Journal 42, 269S-275S, June, 1963

shown in Table II. Bulge strengths decreased with increased travel speed for both as-welded and post-weld aged panels. The strength of panels reheat treated and aged after welding was lower than previously achieved at the commonly used welding speed of 20 inches per minute. Premature failure, particularly in the bulge test, appeared to be associated with small transverse cracks.

Since similar high speed welds in 2219 base metal with 2319 filler and 5456 base metal with 5556 filler did not crack, the need for lower crack sensitive fillers for welding 7175 and 7178 was indicated. With 4145 (10 Si-4 Cu) or 8.5 Mg fillers crack-free welds were achieved in 7178 at speeds up to 80 inches per minutes. Similar sound welds were obtained in 2014 sheet with 4145 or 356 filler. Table III lists the weld properties in 7178 and 2014 at these high travel speeds. At 80 in./min welds in 7178 with 4145 filler were not as strong as welds made at 20 in./min with the stronger X5080 filler listed in Table II. Highest strength in the group, 60 KSI for 7178 MIG welded with 4145 was 10-12 KSI lower than achieved in previous tests with X5080.

The need for a high strength filler with low crack sensitivity led to the development of a 6 Zn-3 Mg alloy, discussed later in this report.

Short-Arc Welding

Another method to reduce the heat affected zone is to use the consumable electrode short-arc (dip transfer) process. In Phase 1 it was reported that individual welds made by this process developed higher strength than welds made by the DC straight polarity tungsten process. Reliability, however, was low because of excessive porosity, undercutting, and poor bead contour.

Using the Linde SVI-500 power supply, which permits separate control over open circuit voltage, slope, and secondary reactance, attempts were made to improve consistency of short-arc welds in 7178 and 7075. Two conditions of chill were selected. One group of welds was made on a copper backing bar having a cylindrical groove 5/32-in. wide to achieve minimum drop-through at the root of the weld and fastest cooling. A second group was run on a similar backing groove 11/32-in. wide, which allowed free drop-through. Figure 2 shows the dimensions of these backups.

Short arc welds of controlled penetration were weaker and less reliable than similar welds made by the DCSP-TIG method or short arc welds made on the larger backing groove that allowed free drop-through. Tensile and bulge properties of welds by both methods are listed in Table IV. Porosity was higher for the welds made with narrow backing. Short-arc welds made with the non-heat treatable Al-Mg filler metals 5556, 5554, 5154, and 5652 were less responsive to post weld aging than similar DCSP-TIG welds and showed a larger difference between "bead on" and "bead off" strengths. This indicated less dilution of filler metal by base metal in short-arc welding than in DCSP-TIG welding. Highest tensile and bulge strengths of welded 7178 were achieved with the DCSP-TIG method using X5080 filler. A heat treatable filler metal such as X5080 must be used to achieve good strength on post weld aging, even on square butt welds in thin sheet.

Since the consumable electrode short-arc method has the advantage of requiring no backing, it could be advantageously used for welded assemblies where it is inconvenient to provide a backup. Nevertheless, it is neither as reliable nor as easily used as the automatic DC straight polarity tungsten process. Since no apparent advantage in welded properties was found, Alcoa continues to recommend the DC straight polarity helium shielded tungsten arc welding as the best method for welding the high strength, heat treatable aluminum alloys. It was used as the standard process for the remainder of this investigation.

Cold Working Welds

Although not strictly a welding procedure, cold working has often been proposed to strengthen welds. It has been used to some extent with the strain hardenable Al-Mg alloys and with certain ferrous metals.

Because commercial planishing equipment was not available, 7178 and 7075 welds were cold rolled to reduce the weld bead to the same thickness as the sheet. Excessive stress in the weld bead caused cracking, particularly with the higher strength filler metals such as X5080. This may be peculiar to square butt welds in 1/8-in. sheet because bead composition is approximately 75 per cent base metal.

Cold work had little or no effect on tensile or bulge strengths of welds in 7178 and 7075. Strengths, listed in Table V, were either equivalent to or less than those previously observed for bead-off welds that had not been cold worked.

Local Heat Treatment of Welds

Brown and Adams[4] showed that the very small interdendritic cell size in weld deposits allows solution heat treatment to be completed in a very short time. Since the weld bead would be stronger if it could be solution heat treated prior to post weld

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4. Paul E. Brown and C.M. Adams, Jr., The Welding Journal 39 (12) Research Supplement, 520-S to 524-S (1960)

aging, an attempt was made to local heat treat welds using the heat from a low current arc.

Direct current, straight polarity tungsten arc welds were made in 1/8-in. 7178-T6 and 7075-T6 sheets using X5080 filler metal. These welds were reheated by an alternating current, argon shielded, tungsten arc at several current levels and travel speeds. Some panels were left clamped in the original jig for reheating and others were insulated from the copper backup using strips of masking tape to provide an insulating air space. The tensile and bulge properties achieved by these welds are shown in Table VI.

After aging, the reheated panels achieved tensile and yield strengths approaching those of conventionally welded and aged joints. Those heated at lowest current and travel speed showed significantly increased tensile elongation and bulge height. Failure in tensile specimens occurred about 1/8-in. from the edge of the weld in the base metal. Failure was transferred from the brittle partially melted zone adjacent the weld to the ductile (although partially annealed) base metal.

Figure 3 shows the structure of DCSP-TIG welded 1/8-in. 7178 given a second pass of 20 v, 50 amps AC current at 20 in./min at low magnification. The originally deposited weld bead and the re-fused area exhibited similar large columnar grain structures. The light crescent shaped band immediately under the re-fused area shows that some solution heat treatment occurred in this area of the original deposit. There are a few small cracks in the originally deposited bead. It is not known whether they existed prior to reheating.

Figure 3a shows, at 500X, the structure of the original weld bead after heating. This structure was similar to that previously observed for as-deposited welds. A visual survey at 500X showed only small differences in interdendritic structures among: (1) the original bead near the root of the weld, (2) the light crescent shaped area in Figure 3, and (3) the area re-fused by the second pass. Complete solution heat treatment was not accomplished in any of the areas. Partial solution treatment, confirmed by the change in contrast, was observed in the light color crescent-shaped area, but the cored structure typical of as-deposited welds was distinguished easily.

Figure 3b shows the partially melted zone adjacent the weld. This area had coarse precipitate, grain boundry melting, and isolated pockets of what appear to be intergranular melting. As expected, this zone showed more partial melting than normally found adjacent one-pass welds. Figure 3c shows the typical over-aged zone about 1/4 in. from the weld.

Figures 4 through 4c show 1/8-in. 7178-T6 welds given a second pass of 20 amps at 20 v, 6-in./min travel speed in an insulated jig. These conditions produced the widest heat affected zone. Figure 4, at low magnification, shows the weld bead had a wider, less distinct band of partial solution heat treatment than in the weld reheated at higher current and faster travel speed. In addition, the refused area at the bead crown had finer grain structure than the originally deposited bead. At higher magnification (Figure 4a) the originally deposited bead had less continuous coring than a typical as-deposited bead, but time and temperature were too short to obtain complete solid solution during the heating by the second pass. The partially melted zone (Figure 4b) exhibited more severe grain boundary melting than appeared in Figure 3b and more depletion in areas adjacent the grain boundary. Figure 4c shows the heat affected zone in the area in which failure occurred in tensile tests. Although no incremental elongation measurements were made, most of the strain shown by substantial necking during testing, occurred in the overaged zone.

It might be argued that the same result achieved by the 2-pass welding could be accomplished by a single pass weld at slow travel speed. Additional tests were made to compare the mechanical properties of 2-pass versus 1-pass welds. These results are shown in Table VII. The heat-affected zone, measured by temperature-indicating lacquer, broadened when heat input was increased and when the work was thermally insulated from the clamping fixture. As the width of the heat affected zone increased, both ultimate and yield strengths were reduced, but tensile elongation increased. Fractures in tensile tests occurred farther from the center of the weld bead. Both bulge strength and bulge height tended to increase with increasing width of heat affected zone.

It was recognized that additional softening of base metal adjacent the weld and the heat treatment of the weld bead, which produced a greater response to post weld aging, were responsible for this behavior. The conditions used for these tests, however, were determined largely by trial and error. A search of available information showed no data for the strength and ductility of 7075-type alloys following short time exposure to temperatures between 500 and 900°F. These properties were needed to predict the optimum local heat treatment thermal conditions for best response to aging.

The Alcoa Marquardt tester was used to heat sheet to precisely controlled temperatures for short periods of time. Samples of

1/16-in. thick 7178, 7075, and two experimental alloyw were resistance heated to temperatures between 500 and 900°F for times between 10 and 60 seconds. Thermocouples attached to the specimens provided an accurate record of the thermal treatment. At the conclusion of the desired heating cycle the samples were air blast quenched at a rate of about 100°F per second. Figure 5 is a photograph of this equipment.

Figures 6 through 9 plot tensile strength, yield strength, and elongation as a function of the temperature to which the sheet was heated. Lowest properties occurred at about 600°F. Tensile strength of 7178 was reduced to approximately 60 KSI and yield strength to 40-45 KSI. Properties decreased slightly with additional time at temperature. At 700°F properties increased slightly, indicating some solution heat treatment. At 850 and 900°F properties essentially equivalent to commercially fabricated and heat treated -T6 tempers were achieved.

The experimental alloys were in the -F (as fabricated) temper when the Marquardt tester was available. Because these materials had little cold work after the last anneal during fabrication, the original low properties were not changed by exposure to temperatures lower than 700°F. Strengths approaching those using conventional heat treatment were achieved at heating temperatures of 850-900°F. For all alloys, strengths at the high temperatures tended to increase with time of exposure, indicating more complete solution heat treatment.

Figure 10 shows a hypothetical weld bead cross section designed to take advantage of the local properties that can be achieved by local heat treatment. The base metal was assumed as 7178-T6, the filler X5080, and the weld bead was locally heated to 900°F, using a flame or other suitable heat source that did not cause remelting of the weld zone. Further, heat input and chill bars were assumed arranged to achieve the temperature distribution shown on the abscissa. The dimensions of the thickened land were chosen to achieve 100 per cent tensile efficiency based on the properties of 7178-T6, shown in Figure 6. Assuming suitable response in the weld bead, the area of lowest apparent yield strength lies well outside the weld in base metal, which should have an elongation of about 15 per cent.

A similar contour could be plotted for full efficiency based on yield strength. Other possibilities include special joint configurations that precisely match thickness with expected strength to achieve uniform strength in all areas.

These empirical tests showed that local heat treatment can have two beneficial effects: First, ductility as measured by both tensile elongation and bulge height is increased by deliberately widening the heat affected zones. The preferred method to achieve this is to use a heat source that does not remelt any of the previously deposited weld metal or cause partial remelting in the base metal. A controlled flame is thought to be a particularly promising method. Second, the longitudinal ductility of the weld bead is improved by solution heat treatment. Transverse failures in bulge tests were avoided, even at the higher bulge heights achieved by local softening of the weld area using the less desirable arc heating in our first tests.

These factors should combine to produce welds in thickened lands that have increased strength and ductility in both longitudinal and transverse loading. Simply welding a thickened land with no post-heat treatment can achieve additional strength in both loading directions and additional ductility in the transverse direction but not increased longitudinal elongation, which is essential to good structural performance under biaxial loads.

Another benefit that should be achieved by local heating of the weld is reduction of residual stresses in the weld area. A particularly effective method would be to combine straightening or sizing operations with post-weld thermal treatment.

Improved Filler Metals

Some joint configurations require a filler metal stronger than X5080. Fillers of 7075 or 7178 composition were known to be too crack sensitive for commercial use. British literature[5,6,7] cited a filler metal of 6 Zn-3 Mg for welding high strength, heat treatable alloys similar to 7075 and 7178.

Three alloys, 6 Zn-3 Mg, 6 Zn-3 Mg-.2 Ti, and 6 Zn-3 Mg-.02 Ti-.004 B were fabricated. Standard cracking tests were used to determine the sensitivity to hot short cracking on 7075-type base metal. Although some investigators report TiB_2 with excess Ti particularly effective in reducing ingot cracking, weld cracking was higher for the Ti-B wire than the 6 Zn-3 Mg wire. The 6 Zn-3 Mg-.2 Ti composition gave the lowest weld cracking. Data for these tests are in Table VIII. All of these compositions cracked less than the previously recommended X5080. The reason for this is that, unlike X5080, these new fillers have a melting range closer to that of the base metal and do not encourage cracking in the parent metal during weld solidification.

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5. Pumphrey and Moore, British Welding Journal 2, No. 5, 206-215, May 1955.
6. British Welding Journal, 319-326, July 1958.
7. British Welding Journal, 360-365, July 1961.

The 6 Zn-3 Mg fillers were used in DCSP-TIG welding of 1/8-in. 7075-T6 and 7178-T6 sheet. The properties of these welds are listed in Tables IXa and IXb. These fillers allowed crack-free welding at travel speeds up to 80 in./minute. Post weld aged joints with these fillers were about as strong as those with X5080 (see Table II) and were essentially unaffected by changes in travel speed. Tensile strength of post-weld solution heat treated specimens markedly improved with increasing travel speed. Although tensile elongations were higher for the reheat treated specimens, both bulge strengths and heights were lower than similar welds made at slow travel speeds. This indicates that the longitudinal ductility of the weld bead was reduced by the high speed welding technique.

At high travel speeds welds contain a significantly higher proportion of filler metal than at low travel speed. The additional filler metal was necessary to avoid undercutting. Composition of the weld beads were more nearly that of the filler metal and contained less copper and chromium than beads deposited at slower speeds. A study of the aging characteristics of ternary Al-Zn-Mg alloys shows that lower temperature aging may be required to achieve best properties under these conditions of dilution.

A filler metal, 8 Zn-2.5 Mg-.5 Mn-.8 Cu, had moderately low sensitivity to weld cracking (Table VIII) on both standard 7075 and 7178 and modified base metal compositions. This filler gave little improvement in as-welded or post-weld aged panels but gave excellent results in reheat treated welds where strength of the joint was not limited by the response of the base metal to post-weld aging.

As a part of an investigation of high purity base metal, which will be discussed later, a high purity 6 Zn-3 Mg-.2 Ti filler was evaluated. This filler (5.87 Zn-2.93 Mg-.01 Mn-.00 Cu-.01 Fe-.01 Si-.00 Cr-.14 Ti) gave strengths and elongations essentially the same as a similar filler with commercial amounts of Fe and Si impurities. This effect was the same when the high purity filler was used on base metals of either commercial or very high purity. There appears to be no advantage for filler metals of very high purity.

In reviewing the microstructure of various weld zones, the question was raised as to whether the melting observed at grain boundaries in the base metal adjacent the weld was ordinary intergranular melting or perhaps penetration of the grain boundaries by liquid metal from the weld puddle. It is known that a microstructure similar to that adjacent to the weld is produced if base metal is merely heated above its solidus temperature. On the other hand, it is also known that metals under stress can be penetrated along grain boundaries by liquid metal.[8] If molten filler metal does penetrate the grain boundaries of the base metal, the chemical composition of the filler can have an effect on the properties of partially melted base metal as well as the weld bead itself.

To determine whether filler metal penetrated the base metal adjacent the weld, high purity (0.01 Si) 7075 base metal was welded with 4043 (5 Si) filler and sections of the weld were analyzed using the electron microprobe. This combination of filler and base metal was chosen to permit easy identification of filler metal

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8. Rostoker, McCaughey, Markus; "Embrittlement by Liquid Metals," 1960, Reinhold.

penetration into base metal. Two welding methods, one an automatic weld having a minimum heat affected zone and the other a manual weld having a wide heat affected zone, were investigated.

The microprobe was calibrated to record simultaneously the intensities of Si, Cu, and Mg. Polished weld cross-sections were analyzed at 30 micron intervals and the contamination mark was allowed to form on alternate spots so that reference could be made to the analyzed region on the photomicrographs of the samples (Figures 11 and 12). The concentrations of Cu, Mg, and Si determined at each analytical site were plotted as a function of location in the weld area.

The analyzed volume in all cases was larger than any individual particle, and the observed concentrations were not corrected for absorption effects. The concentrations shown for the weld zone, therefore, do not represent either particle or matrix but rather a sampling of both--in relative rather than absolute concentrations. The observed copper concentration is closest to actual composition since absorption of copper radiation by other elements is very low. The parent metal, which contained 1.39 per cent Cu by conventional analysis, gave 1.44 per cent by microprobe analysis. Magnesium radiation is absorbed. The observed concentration by the microprobe was 1.84 per cent rather than the 2.40 per cent determined by conventional analyses. The observed concentrations were sufficient to allow intelligent interpretation, and the experimentally observed concentrations were not adjusted.

Figure 13 shows the large variations in the relative concentrations of copper and magnesium revealed by traversing the microprobe across the automatic weld bead into the base metal. Silicon also fluctuated but decreased with increasing distance from the cast-wrought interface. Silicon was detected to a point corresponding to about 4.5 on Figure 11, which is well into the base metal. Copper and magnesium became uniform at about 7.5, which corresponds to the end of the heat affected zone and the start of the normal base metal.

The manual weld, Figure 14, showed the same general picture except that both variations in magnesium and copper, as well as the presence of silicon, were observed a greater distance into the base metal. Silicon particles were detected to a point approximately between 10-1/2 and 11 on Figure 12. This represents a penetration of silicon of about 18 mils into the partially melted base metal.

Silicon penetration correlated roughly with the extent of major variations in copper and magnesium. Therefore, it seems likely that silicon penetration extended approximately the same distance from the weld as partially melted base metal. (Minor variations in copper and magnesium probably are caused by precipitation from solid solution rather than partial melting.) Penetration of base metal by silicon-containing filler metal may be liquid metal penetration abetted by thermally induced stresses or merely dilution of the partially melted parent metal by filler metal. In either case, filler metal composition appears to have a greater effect on strength and ductility of the partially melted base metal than was previously thought.

This observation may help explain the improved ductility of welds made with high zinc, copper-free, filler metal because the partially melted grain boundaries should contain less copper. Previous work with both the modified 7075 type alloys (.8 Cu) and copper-free alloys such as lower strength X7006 confirmed that weld ductility was improved by reducing or eliminating copper in Al-Zn-Mg alloys.

Additional tests are needed to firmly establish the effect of filler metal composition on the composition of the partially melted base metal adjacent the weld. A clearer understanding of the mechanisms involved will be helpful in the development of improved filler metal compositions.

Reducing Local Stresses

In Phase 1 report it was shown that most welded assemblies in the high strength, heat treatable aluminum alloys lacked sufficient ductility to allow local yielding to relieve the high local stresses generated by differential thermal expansion and mechanical mismatch. Both welded cylinders and bulge tests of flat panels failed at low nominal stresses because local high stresses were not relieved.

To confirm this observation, strain gages were mounted on bulge test specimens of 7178-T6 welded with 5556. Failure was expected at about 57 KSI. Bulge tested panels failed, however, at 32 KSI, about 25 KSI lower than stress calculated by the standard membrane formula. Strain gages showed that local stresses equivalent to those observed for failure in the tensile tests were developed locally in the bulge test. These stresses were generated by a combination of residual stresses, the hydraulic bulging pressure, clamping pressure, and resistance to bending in the test apparatus. Data for welded and unwelded sheet are shown in Figures 15 and 16 respectively.

Because high local stresses cause premature failure, it was thought they might be eliminated by welding 7178 in the -W temper, prestretching or sizing while the material was in the soft condition, then aging the assembly. If sufficient yielding could be achieved by this process to relieve the mechanically and thermally induced stresses, stress at failure in a welded structure or bulge test should more closely approach that observed for simple tensile specimens. To obtain significant stress relief, it is essential the tensile strength of the weld be higher than the yield strength of the surrounding base metal.

Some investigators have shown that certain steels are strengthened by stretching at -320°F and have applied this technique to welded cylinders with good results. Stretching up to 5 per cent at either room temperature or -320°F had no significant effect on the properties of 7178-W subsequently aged to -T6. Unless stretching at -320°F has some unexpected benefit in the weld area, no improvement in the strength of welded 7178 should be achieved by stretching at -320°F, because the base metal is already significantly stronger than the weld area and the ductility of the weld area would be expected to decrease rather than increase at cryogenic temperatures. It was decided no further tests should be made at sub-zero temperatures.

Stretching at moderately elevated temperatures should be more beneficial for welded assemblies because a higher bulge at the lowered yield strength would be expected. No facilities were available to try this technique. Room temperature stretching of weld panels of 1/8-in. thick 7178-W sheet was evaluated: (1) prior to aging, (2) after periods of natural aging, and (3) between steps of the 2-step aging treatment. Stretching was accomplished by pre-bulging as high as 0.4 in. in the bulge tester.

Panels stretched prior to aging developed bulge strengths of about 60 KSI and 0.5 in. height, an improvement in strength and height of 5-10 KSI and 0.2 in., respectively, compared to panels aged without intermediate stretching.

Panels stretched after natural aging for 1 and 14 days at room temperature had bulge properties about 55 KSI, 0.4 in. height (.5 per cent elongation). Base metal yield strength, measured by conventional tensile test, increased from 44 KSI with one day natural aging to 55 KSI after 14 days. Although bulge strength and height were almost identical for 1 and 14 days natural aging, base metal yield strength after 14 days aging was almost the same as the tensile strength of the welds aged a similar period. Thus, welds should be stretched as soon as possible after welding to achieve the highest degree of mechanical stress relief without danger of weld failure during stretching.

Some panels were stretched between steps of the 2-step aging treatment. Tensile tests from the same panels were included for comparison, although the tensile coupons were not stretched prior to aging. The properties of both stretched and unstretched welds are listed in Table X.

Bulge strengths achieved by stretching between step aging treatments were essentially the same as those previously reported for unstretched welds. Bulge height was slightly greater than before but represented a very small increase over the height to which the panels were prestretched. Bulge strengths were about the same among the various filler metals, although tensile strengths increased slightly for fillers of higher zinc content.

Nearly all specimens welded with the higher zinc content filler metals failed transverse to the weld at the periphery of the test panel. This indicated low ductility in the weld bead because the panels were unable to bend without failure over the 1-in. radius die entry (8T for 1/8-in. sheet).

Welds made with X5080 filler did not fail in a transverse manner. Improved performance of welded 7178, under biaxial stress, and where bending occurs in structures, is attained by deposition of a more ductile weld bead such as with X5080.

Improved Base Metals

It has been proposed that welds in high strength alloys 7075 and 7178 would be improved if the levels of Fe and Si were reduced. Such materials have shown increased resistance to spalling in ballistic tests, have higher tear resistance, and somewhat greater ductility than similar alloys containing the commercial amounts of Fe and Si.

Welds in alloy 7075 for four levels of purity and 7178 of three purity levels were evaluated in both solution heat treated and aged and post-weld aged only conditions. Properties of these welds are listed in Table XI.

Bulge strength and height were significantly increased for the reheat treated 7075-type alloys. Highest bulge properties were attained in base metal having Fe in the 0.02-0.09 range and Si from 0.06-0.10. No significant improvement was evident in either reheat treated or post-weld aged high purity 7178.

The very high purity 7075 and 7178 generally gave lower bulge properties than intermediate purity compositions of these alloys. Tensile properties were not significantly affected by base metal purity. It is known that these high purity metals are more difficult to cast, and it seems possible they were somewhat more susceptible to microcracking in the partially melted zone adjacent to the weld. Cracks, if present, were not large enough to be detected during radiographic examination.

A previous Alcoa-funded investigation showed that 7075 type alloys of controlled composition (low Cu and Mn substituted for Cr) gave improved strengths in reheat treated welded structures. The tensile and bulge test properties of welds in three such alloys of varying purity with respect to Fe and Si are listed in Table XII. Purity had little effect on weld tensile strength, yield strength, or uniaxial elongation, as previously observed for high purity 7075. Filler metal compositions were not critical.

In bulge tests, however, both strength and ductility improved noticeably with increased purity of the base metal. For the welding parameters and filler-base metal dilution in these tests, highest purity base metal welded with either M577 or the 8-Zn filler metal gave best strength and ductility.

Susceptibility to hot short cracking for both the standard 7075 and 7178 base metals and the low copper alloys with the several filler metals investigated are shown in Table XIII. For the high purity 7075 type alloys welded with base metal fillers, hot short cracking increased with increasing purity. Filler alloys M743 (6 Zn-3 Mg-.2 Ti) and 253519 (8 Zn-2.5 Mg) gave the lowest amount of hot short cracking for both the low copper alloys and the standard 7075 and 7178 base metals. X5080 developed the greatest amount of cracking. This filler would be less desirable in 7075 and 7178 for fillet and repair welds (which the weld cracking tests simulate) because heat flow more nearly approximates equilibrium conditions and allows base metal of lower melting range than the filler metal to be the last to solidify. In actual butt welding of sheet, sensitivity to cracking is low because heat flow conditions prevent cracking at the edge of the weld. Therefore, filler X5080 is a good choice for butt welds in sheet gage 7075-type alloys when the weld bead reinforcement can be left intact. Weld beads are reasonably ductile. Wire can be fabricated commercially. Response to either post weld aging or solution heat treatment and aging is excellent because of the dilution achieved in these welds.

Fillers of higher strength than X5080 are needed for welds in sheet with the bead removed and for plate with V-groove edge preparation. Wither M743 or the 8 Zn-2.5 Mg filler may be used for these applications. The latter filler is preferred for highest strength and ductility. Corrosion characteristics of these higher zinc filler metals remain to be determined.

Resistance to Corrosion

The solution potential surveys reported in Phase 1 predict that post weld aging should improve the corrosion resistance of welded 7075 and 7178. The potentials of the weld bead and the heat affected zone 1/8 in. away were less anodic after aging, so it was expected that preferential attack of the weld area should be reduced.

To determine actual corrosion characteristics, welded 7075 and 7178, both as-welded and post-weld aged, were exposed to 3-1/2 per cent NaCl alternate immersion (indoors, 10 min in, 50 min out) in both stressed and unstressed conditions. Stressed specimens were assembled in pairs, as shown in Figure 17. Evaluations were: (1) visual, (2) loss of strength after 12 weeks exposure unstressed, (3) days to failure in the stressed condition, (4) loss of strength in stressed specimens that did not fail during a 12-week exposure.

Table XIV compares the stress corrosion performances of 7075-T6 and 7178-T6 welded with X5080, for the several post weld aging treatments known to give good mechanical properties. Aging 24 hrs at 212°F provided a modest increase in strength yet retained the good resistance to stress corrosion cracking typical of as-welded joints. The intermediate aging, one week at 212°F, tended to increase susceptibility to stress corrosion, particularly when the applied stress during exposure was increased from 50 per cent of the tensile strength to about 70 per cent. The best combination of strength and resistance to corrosion in this group was welded 7178 aged 8 hr at 212°F + 3 hr at 325°F. The week at 212°F and the 4 hr at 212°F + 8 hr at 315°F treatments gave about equivalent strength and resistance to stress corrosion cracking, but general resistance to corrosion was superior for the 2-step aging.

Several aging treatments were surveyed to determine if slightly more aging would improve corrosion resistance with little detrimental effect on strength. Three levels of stress were selected to determine the effect of stress on failure by stress corrosion and loss of properties during exposure. These results are shown in Table XV.

Little difference in susceptibility to stress corrosion cracking or loss of strength after exposure was noted among the several aging treatments. In the 12-week test failures always occurred at 45 KSI stress--never at 15 KSI--sometimes at 30 KSI. Because of the non-uniform attack, loss of strength sometimes was greater for unstressed specimens than those stressed at 15 KSI. More tests will be required to obtain reliable data. The non-uniform attack is illustrated in Figures 18, 19, and 20.

Some tentative conclusions may be drawn from these preliminary tests. With equivalent post weld aging, welded 7178-T6 is stronger and more resistant to corrosion than welded 7178-W. Good resistance to stress corrosion cracking at sustained stresses about 30 KSI or lower is achieved in both as-welded and post-weld aged 7178-T6 and 7075-T6. The aged welds had less severe attack in the heat affected zone but more severe local attack in the weld metal and the weld metal-base metal interface.

Alcoa-funded investigations showed that both strength and corrosion resistance can be improved by solution heat treating and aging after welding. This treatment is recommended for small structures where it is practicable. Some accelerated attack of the weld occurs even under these optimum conditions. A good protective coating for welded 7178 or 7075 with any post-weld treatment is recommended if a corrosive service environment is anticipated.

CONCLUSIONS

1. Sheet gage 7075 and 7178, welded with X5080 achieve a good combination of strength and resistance to corrosion when welded in the -T6 temper, then aged 8 hours at 212°F + 3 hours at 325°F.

2. Ductility of welds in 7075 and 7178 was improved by locally heating the weld with a low power arc before aging.

3. High strength fillers such as 6 Zn-3 Mg-.2 Ti and 8 Zn-2.5 Mg-.5 Mn-.8 Cu improved strength of reheat treated welds in 7075 and 7178. Properties of as-welded or post-weld aged joints were not improved. These new fillers are promising for repair welds, because melting ranges lower than X5080 reduce the possibility of edge cracking in the base metal.

4. Base metals of 7075 type with low Fe and Si and/or Cu at 0.8 per cent rather than 1.5 gave higher strength and ductility than standard 7075 and 7178 in reheat treated welds. Strengths of as-welded or aged joints were unaffected.

5. Increasing the travel speed in DCSP-TIG welding 7075 and 7178 decreased strength because of higher filler-base metal dilution and transverse cracking.

6. Short-arc welds were improved by a more flexible power source but in our tests were not as reliable as DCSP-TIG welds.

7. Welds in 7075 and 7178 were difficult to cold work without cracking and were not strengthened by working before aging.

8. Molten filler metal penetrates or alloys with partially melted base metal at the edge of welds and can influence the properties of this area.

9. Strain gage instrumented bulge tests confirmed the theory that welds in 7178 often fail at low nominal stress because low ductility does not permit yielding to relieve residual and clamping stresses.

10. Welding 7178 in -W temper, then pre-bulging (stretching) improved correlation between tensile and bulge strengths. This technique may be applicable to some welded structures. Improved treatments are required, however, to raise strength and resistance to corrosion of 7178 welded in -W temper, then aged.

RECOMMENDATIONS

It is recommended that future work be directed toward these promising areas:

1. Investigate weldability of new Al-Zn-Mg alloys of higher Zn and lower Cu than 7178 and 7075.
2. Refine local heat treating procedures to improve weld strength and ductility.
3. Develop filler metals of the 6-8 Zn, 2-4 Mg type to reduce crack sensitivity and improve longitudinal weld elongation.
4. Survey new test methods and devise design rules for welded high strength aluminum alloy structures.
5. Improve low heat input gas metal arc welding methods.

TABLE I

NOMINAL COMPOSITIONS--BASE AND FILLER METALS

Base Metals

Alloy	Cu	Si	Mn	Mg	Zn	Cr	Ti	V	Zr	Other
7075	1.6	---	---	2.5	5.6	0.30	---	---	---	---
7178	2.0	---	---	2.7	6.8	0.30	---	---	---	---
2014	4.4	0.8	0.8	0.4	---	---	---	---	---	---
2024	4.5	---	0.6	1.5	---	---	---	---	---	---
2219	6.3	---	0.3	---	---	---	---	0.10	0.15	---
5456	---	---	0.8	5.25	---	0.10	---	---	---	---
X7006	---	---	0.2	2.25	4.25	0.10	---	---	---	

Filler Metals

Alloy	Cu	Si	Mn	Mg	Zn	Cr	Ti	V	Zr	Other
5556	---	---	0.8	5.25	---	0.10	0.10	---	---	---
5554	---	---	0.8	2.75	---	0.10	0.10	---	---	---
X5080	---	---	0.5	4.0	2.0	0.10	0.10	---	---	---
5356	---	---	0.10	5.0	---	0.10	---	---	---	---
2319	6.3		0.3	---	---	---	0.15	0.10	0.15	---
4145	4	10	---	---	---	---	---	---	---	---
5154	---	---	---	3.5	---	0.25	---	---	---	
5652	---	---	---	2.5	---	0.25	---	---	---	High purity 5052
B (M743)	---	---	---	3.0	6.0	---	0.2	---	---	
4043	---	5.0	---	---	---	---	---	---	---	
M577	---	---	0.10	4.0	4.0	0.10	0.12	---	---	
356	---	7	---	0.3	---	---	---	---	---	
8.5 Mg	---	----	0.3	8.5	---	0.10	---	---	---	

TABLE II

WELD PROPERTIES AS A FUNCTION OF TRAVEL SPEED
DCSP-TIG, He

1/8" 7178-T6, X5080 Filler

Travel Speed in./min	Volts	Amps	Post-Weld Treatment	Tensile Test* TS KSI	YS KSI	% El 2"	Bulge Test* Str KSI	Hgt in.
20**	12.0	200	A	70	68	1.0	58	0.42
30	12.5	180	A	67.6	67.0	0.5	-	-
40	12.5	280	A	61.5	-	"	40.0	0.33
60	14.5	350	A	59.1	-	"	41.7	0.33
80	15.5	360	A	55.4	-	"	37.8	0.35
20**	12.0	200	None	57	53	1.0	46	0.42
60	14.5	350	None	49.9	-	1.0	43.0	0.39
80	15.5	360	None	52.5	-	0.5	43.3	0.38
20**	13.0	230	RHT -T6	86.6	81.6	2.8	67.6	0.47
80	15.5	360	RHT -T6	76.4	-	1.0	50.0	0.42

1/8" 7075-T6, X5080 Filler

Travel Speed in./min	Volts	Amps	Post-Weld Treatment	Tensile Test* TS KSI	YS KSI	% El 2"	Bulge Test* Str KSI	Hgt in.
20**	12.0	200	A	61	-	1.2	47	0.38
60	14.5	350	A	55.2	-	1.0	44.6	0.41
80	15.5	360	A	57.8	-	1.0	42.3	0.42
20**	12.0	200	None	50	48.0	1.0	43	0.41
80	15.5	360	None	56.1	-	1.0	47.8	0.43
20**	13.0	230	RHT -T6	85	75	5.0	68	0.50
80	15.5	360	RHT -T6	86.7	75.2	10.0	63.0	0.50

*Bead on
**Phase Report 1

A - Aged 8 hr at 212°F + 3 hr at 325°F

TABLE III

WELD PROPERTIES, 2024 and 7178, 80 in./min USING FILLERS OF LOW CRACK SENSITIVITY

Base Metal	Weld Method	Filler* Metal	Post Weld Treat	Bead On TS KSI	Bead On YS KSI	Bead On %El 2"	Bead On Bulge Str KSI	Bead On Bulge Hgt In.	Bead Off TS KSI	Bead Off YS KSI	Bead Off %El 2"	Bead Off Bulge Str KSI	Bead Off Bulge Hgt in.
2014-T6 .125"	MIG	4145	A	50.6	45.6	1.3	47.8	0.49	49.0	43.8	1.2	45.6	0.41
"	DCSP-TIG	4145	A	51.7	48.1	0.9	51.2	0.47	49.6	45.4	1.3	50.5	0.46
"	"	356	A	51.0	47.1	1.1	52.1	0.50	47.3	43.7	1.4	42.9	0.37
7178-T6 .090"	MIG	4145	B	60.1	-	0.5	45.7	0.41	53.6	52.3	0.5	40.6	0.37
"	DCSP-TIG	4145	B	58.9	-	0.8	49.6	0.42	51.6	48.2	0.9	50.8	0.42
"	"	8.5 Mg	B	59.2	-	0.5	49.7	0.41	55.9	-	0.8	38.6	0.31

*Filler metal compositions are listed in Table I

A - Aged 10 hrs at 375°F
B - Aged 8 hrs at 212°F + 3 hrs at 325°F

TABLE IV

COMPARISON OF DCSP-TIG AND MIG SHORT ARC WELDS
0.090" 7178-T6 SHEET

				Tensile Test						Bulge Test*	
				Bead On			Bead Off				
Welding Method	Back-up Groove	Filler Metal	Post-Weld Treatment	Avg TS KSI	%El 2"	No. of Tests	Avg TS KSI	%El 2"	No. of Tests	KSI	Hgt. in.
DCSP-TIG	5/32	5556	A	64	1.0	4	62	-	4	53	0.46
MIG-SA	"	"	A	54.8	1.7	3	47.4	1.5	3	47.3	0.37
DCSP-TIG	5/32	X5080	B	73	0.9	4	69	-	4	52	0.45
MIG-SA	"	"	"	58.1	3.0	2	52.7	1.3	3	56.6	0.47
MIG-SA	11/32	"	"	63.6	1.0	4	59.9	1.0	4	57.3	0.39
DCSP-TIG	5/32	X5080	C	68.7	1.0	3	62.7	2.0	2	59.7	0.45
MIG-SA	"	"	"	57.7	1.2	3	47.5	-1.8	3	52.4	0.40
MIG-SA	11/32	"	"	59.3	1.0	4	52.7	1.0	4	55.8	0.38
MIG-SA	5/32	5554	A	51.0	1.3	3	43.1	1.3	3	44.5	0.36
MIG-SA	5/32	5154	"	47.9	1.5	3	41.1	1.5	2	46.5	0.40
MIG-SA	11/32	"	"	57.8	1.0	4	53.1	1.5	4	57.8	0.42
MIG-SA	5/32	5652	"	46.2	2.0	3	38.2	1.0	3	45.4	0.40
MIG-SA	11/32	"	"	54	1.5	3	-	-	-	57	0.42

*Bulge Test - Bead off; values listed are averages of two tests

A - Aged 4 hrs at 212°F + 8 hrs at 250°F
B - Aged 4 hrs at 212°F + 8 hrs at 315°F
C - Aged 24 hrs at 212°F

TABLE V

PROPERTIES OF DCSP-TIG WELDS IN 1/8" 7178-T6 AND 7075-T6 WITH BEAD COLD ROLLED FLUSH

Parent Metal	Filler Metal	Internal Between Welding & Rolling	Tensile Tests TS KSI	YS KSI	% El (2")	Bulge Tests Str KSI	Height in.
7178	X5080	<2 hrs.	63.6	-	0.6	43.9	0.34
7178	X5080	1 day	64.5	-	0.5	44.0	0.35
7178	X5080	No rolling	70	68	1.0	58	0.42
7178	5554	<2 hrs.	62.3	-	0.5	33.0	0.26
7178	5554	1 day	62.1	64.3*	0.9	47.6	0.34
7178**	5554	No rolling	73	71.8	1.0	34.9	0.35
7075	5554	<2 hrs.	61.0	60.2	0.7	46.9	0.38
7075	5554	No rolling	56	47	1.0	52	0.42

*Individual value accompanying TS 64.5 KSI
Others failed before 0.2% offset.

Welds aged 24 hours at 212°F after cold rolling.

**Aged 1 week at 212°F

TABLE VI

PROPERTIES OF REHEATED DCSP-TIG WELDS IN 1/8" 7178-T6 WITH X5080 FILLER

Second Pass Amps	Second Pass Travel in./min	TS KSI	YS KSI	% El 2"	Bulge Strength KSI	Bulge Height in.
Not reheated		70	68	1.0	58	0.42
50	20	68	62	2.0	38	0.38
35	15	68	62	1.0	32	0.38
35	10	69	62	1.0	36	0.37
25	5	67	56	2.0	42	0.42
*50	20	64	61	1.5	39	0.33
*35	15	69	62	1.0	36	0.31
*25	10	66	58	1.5	44	0.39
*20	6	65	45	2.5	55	0.52

*Panel thermally insulated from backup for second pass.

Note: First pass 12.5 volts, 190-210 amps DC, 20"/min, heated by second pass, then aged 8 hrs at 212°F + 3 hrs at 325°F. Second pass AC, 20 volts, amps and travel speed as noted. All tests bead on.

TABLE VII

PROPERTIES OF 2-PASS VERSUS 1-PASS WELDS IN 1/8" 7178-T6 AND 7075-T6 SHEET FILLER METAL - X5080

Base Metal	1st Pass, DCSP-TIG Amps	V	Travel in./min	Jig *	2nd Pass, AC-TIG Amps	V	Travel in./min	Jig *	Width-HAZ** in. at 300°F	600°F	Tensile Test Bead	TS KSI	YS KSI	%El 2"	Bulge Test Str KSI	Hgt in.
7178	200	13.0	20	S	15	20	5	I	1.13	.63	On	64.1	-	.5	32.4	.30
"	"	"	"	"	"	"	"	"	"	"	Off	66.7	62.7	1.0	50.1	.47
"	190	12.8	5	"	No 2nd pass			-	2.0	.79	On	62.8	57.3	1.0	42.6	.37
"	"	"	"	"	"	"		-	"	"	Off	60.6	53.5	1.75	59.0	.55
"	175	13.0	"	I	"	"		-	2.56	1.22	On	61.9	51.0	1.4	30.9	.30
"	"	"	"	"	"	"		-	"	"	Off	60.5	51.0	2.0	59.9	.58
7075	210	"	20	S	15	20	5	I	1.13	.63	On	62.2	-	.5	39.1	.34
"	"	"	"	"	"	"	"	"	"	"	Off	61.3	56.3	1.75	52.8	.47
"	180	13.5	5	"	No 2nd pass			-	2.00	.79	On	56.3	54.1	.75	40.9	.35
"	"	"	"	"	"	"		-	"	"	Off	55.9	48.7	2.10	56.3	.57
"	175	13.0	"	I	"	"		-	2.56	1.22	On	62.7	53.2	2.0	48.9	.42
"	"	"	"	"	"	"		-	"	"	Off	55.3	47.8	2.0	54.6	.54

*S = Solid, I = Insulated
**HAZ = Heat affected zone

Panels post-weld aged 8 hrs at 212°F + 3 hrs at 325°F

TABLE VIII

CRACK SENSITIVITY OF EXPERIMENTAL
FILLER METALS ON 7075-TYPE BASE METAL

Filler	Inches of Cracking Continuous Test	Inches of Cracking Discontinuous Test
6 Zn-3 Mg	1	16
6 Zn-3 Mg-.03 Ti-.003 B	3.5	17
6 Zn-3 Mg-.2 Ti	0	15
X5080 (2 Zn-4 Mg-.5 Mn-.1 Ti)	22*	--
8 Zn-2.5 Mg-.8 Cu-.5 Mn	2	--

*Cracked in base metal at one or both edges of fillet. Total cracking reported

TABLE IXa

PROPERTIES OF 1/8" 7178-T6 DCSP-TIG WELDED WITH 6 Zn-3 Mg FILLERS

Post-Weld* Treatment	Filler**	Weld Speed in./min	Bead	TS KSI	YS KSI	% El (2")	Bulge Strength KSI	Bulge Height (in.)
Age	A	17	on	65	--	0.6	46	.36
"	"	"	off	65	62	1.2	45	.40
Age	B	20	on	65	--	0.5	46	.37
"	"	"	off	65	62	1.1	47	.40
Age	C	20	on	68	--	0.5	45	.35
"	"	"	off	67	64	1.5	39	.35
Age	B	80	on	62	--	0	40	.32
"	"	"	off	59	--	0.5	42	.37
Age	C	80	on	59	--	0.2	37	.33
"	"	"	off	64	63	0.8	38	.36
RHT	A	17	on	86	78	2.8	50	.39
"	"	"	off	83	77	2.9	79	.79
RHT	B	20	on	88	79	3.4	66	.52
"	"	"	off	85	77	3.8	82	.87
RHT	C	20	on	86	79	2.8	45	.35
"	"	"	off	85	77	3.4	72	.62
RHT	B	80	on	90	79	5.4	49	.43
"	"	"	off	80	76	1.6	55	.44
RHT	C	80	on	90	79	7.0	58	.47
"	"	"	off	85	79	3.4	52	.46

*Age = 8 hrs at 212°F + 3 hrs at 325°F
RHT = 1 hr at 880°F, cold water quench, age 24 hrs at 250°F

**A = 6 Zn-3 Mg
B = 6 Zn-3 Mg-.02 Ti-.004 B
C = 6 Zn-3 Mg-.2 Ti

TABLE IXb

PROPERTIES OF 1/8" 7075-T6 DCSP-TIG WELDED WITH 6 Zn-3 Mg FILLERS

Post-Weld* Treatment	Filler**	Weld Speed in./min	Bead	TS KSI	YS KSI	% El (2")	Bulge Strength KSI	Bulge Height (in.)
Age	A	17	on	65	63	0.6	40	.38
"	"	"	off	63	58	1.6	41	.38
Age	B	20	on	66	65	1.0	47	.37
"	"	"	off	65	60	1.8	48	.44
Age	C	20	on	64	--	0.6	43	.34
"	"	"	off	62	61	1.5	44	.40
Age	B	80	on	62	--	0.6	43	.36
"	"	"	off	62	59	1.4	41	.37
Age	C	80	on	63	--	0.8	47	.40
"	"	"	off	63	59	1.5	40	.36
RHT	A	17	on	84	74	5.1	64	.53
"	"	"	off	80	73	3.6	62	.54
RHT	B	20	on	83	75	3.5	72	.60
"	"	"	off	81	73	4.6	78	.97
RHT	C	20	on	82	74	3.6	71	.61
"	"	"	off	81	73	5.3	75	.82
RHT	B	80	on	87	76	6.0	51	.40
"	"	"	off	80	74	3.6	60	.50
RHT	C	80	on	87	76	6.4	64	.50
"	"	"	off	80	76	2.5	59	.48

*Age = 8 hrs at 212°F + 3 hrs at 325°F
RHT = 1 hr at 880°F, cold water quench, age 24 hrs at 250°F

**A = 6 Zn-3 Mg
B = 6 Zn-3 Mg-.02 Ti-.004 B
C = 6 Zn-3 Mg-.2 Ti

TABLE X

PROPERTIES OF STRETCHED AND UNSTRETCHED WELDS IN 1/8" 7178-W SHEET

(Two Bulge, Four Tensile Tests Each Combination)

Filler Metal*	Weld Method	Bead	Tensile Tests (No Stretching) TS KSI	YS 2" KSI	%El 2"	Bulge Tests Pre-bulge Inches	Bulge Str. KSI	Bulge Hgt. in.
Pre-Bulged Before Aging								
X5080	DCSP-TIG	On	59.2	-	0.5	.34	57.3	.38
"	"	Off	63.8	59.3	1.9	"	57.9	.43
265753	"	On	68.1	-	0.6	.34	58.4	.40
"	"	Off	66.5	63.2	1.0	"	52.3	.37
253519	"	On	69.0	-	1.0	"	56.6	.35
"	"	Off	67.3	63.9	1.4	"	57.6	.38
265576	MIG-Short Arc	On	49.8	-	0.5	.14	Failed in pre-bulge	
"	"	Off	58.5	-	0.6	.34	60.9	.41
Pre-Bulged Between Aging Steps								
X5080	DCSP-TIG	On	60.3	-	0.5	.34	53.3	.35
"	"	Off	64.5	61.1	1.1	"	55.2	.37
265753	"	On	68.7	-	1.0	"	51.5	.37
"	"	Off	67.0	63.8	1.0	"	52.5	.38
253519	"	On	65.3	-	1.0	.3	Failed in pre-bulge	
"	"	Off	68.5	65.0	1.5	.2	54.2	.30
265576	MIG-Short Arc	On	46.5	-	0.6	.10	Failed in pre-bulge	
"		Off	56.2	-	0.9	.28		

Post-weld Treatment - step aged 8 hrs at 212°F + 3 hrs at 325°F

*265576 = 6 Zn-3 Mg-.2 Ti
253519 = 8 Zn-2.5 Mg-.5 Mn-.8 Cu
265753 = 6 Zn-3 Mg-.5 Mn-.05 Cu-.2 Ti
X5080 = 2 Zn-4 Mg-.5 Mn-.1Ti

TABLE XI

PROPERTIES OF VARIOUS PURITY - 7178 AND 7075
1/8-IN. -T6 TEMPER SHEET, DCSP-TIG WELDED, X5080 FILLER

Parent Metal	Fe	Si	Post Weld Treatment	Bead On TS KSI	Bead On YS KSI	Bead On % El 2"	Bead Off TS KSI	Bead Off YS KSI	Bead Off % El 2"	Bulge Test Bead on Bulge Str KSI	Bulge Test Bead on Bulge Hgt in.
7075 type	.00	.00	Age (1)	67.6	66.1	0.6	60.9	55.1	1.9	48.9	0.39
"	.03	.06	"	63.3	-	0.7	60.4	55.2	1.9	49.4	0.40
"	.09	.08	"	64.0	-	0.9	62.7	58.8	1.6	46.3	0.37
Std 7075*	.22	.10	"	61	-	1.2	60	57	1.6	47	0.38
7075 type	.00	.00	RHT -T6	83.9	75.0	5.4	77.8	71.4	4.6	75.0	0.63
"	.03	.06	"	83.8	74.8	6.9	74.9	69.3	3.5	81.3	0.83
"	.09	.08	"	83.4	75.8	4.2	79.1	72.4	3.8	76.2	1.01
Std 7075*	.22	.10	"	85	75	5	-	-	-	68	0.50
7075 type(M697)	.01	.01	Age (2)	62.0	-	0.7	59.9	56.1	1.8	46.5	0.39
7178 type	.00	.00	Age (1)	60.8	-	0.6	62.7	58.8	1.6	42.1	0.32
"	.02	.06	"	66.0	-	0.5	66.2	61.9	1.3	45.0	0.35
"	.09	.08	"	62.5	-	0.5	64.3	62.7	1.2	46.7	0.34
Std 7178*	.20	.09	"	70	68	1.0	64	58	1.3	58	0.42
7178 type	.00	.00	RHT -T6	89.2	81.9	2.4	85.3	78.6	3.0	62.7	0.43
"	.02	.06	"	86.6	82.0	1.4	86.3	79.1	3.8	72.6	0.52
"	.09	.08	"	86.6	81.6	1.8	85.2	78.6	2.1	64.5	0.47
Std 7178*	.20	.09	"	86.6	81.6	2.8	-	-	-	67.6	0.47

*Previous tests, average values

Age (1): 8 hr at 212°F + 3 hr at 325°F
Age (2): 168 hr at 212°F

Weld conditions: 12.5-13.5 volts; 190-200 amperes; 20 ipm travel speed; helium shielding.

TABLE XII

PROPERTIES OF 1/8" DCSP-TIG WELDED MODIFIED 7075-TYPE ALLOYS

Base Metal	Filler	Bead	Avg-4 Tests Tensile Tests TS KSI	YS 2" KSI	% El 2"	Avg-2 Tests Bulge Tests Str KSI	Hgt (in.)
253518	253518	On	72.8	65.5	9.3	69.0	1.03
	"	Off	71.8	64.5	6.8	70.5	1.04
	253519	On	73.3	65.3	9.1	74.2	1.0
	"	Off	72.5	64.4	8.4	78.0	1.18
	M577	On	73.3	66.2	9.9	79.4	1.90
	"	Off	71.9	65.2	6.8	75.1	.96
	M743	On	72.5	65.0	8.6	79.1	1.38
	"	Off	71.3	64.8	5.2	73.8	.64
253517	253517	On	74.4	67.6	10.1	70.9	.94
	"	Off	74.0	67.2	8.3	72.8	.93
	253519	On	74.8	68.2	9.0	73.0	1.14
	"	Off	74.2	68.0	7.5	74.2	1.02
	M577	On	74.4	67.3	8.7	75.5	1.23
	"	Off	72.4	65.5	5.9	75.2	.95
	M743	On	73.6	66.4	10.0	68.0	.43
	"	Off	70.5	65.4	5.4	69.4	.77
253516	253516	On	72.8	66.0	9.6	76.0	.63
	"	Off	72.3	65.2	7.9	76.2	.56
	253519	On	74.2	66.9	8.6	69.6	.71
	"	Off	73.8	66.7	7.6	67.7	.77
	M577	On	74.0	65.8	9.5	69.9	1.37
	"	Off	70.9	63.8	7.4	71.7	1.15
	M743	On	73.3	65.3	9.1	77.0	1.26
	"	Off	72.8	65.3	7.6	76.9	.66

Compositions

Alloy	Cu	Fe	Si	Mn	Mg	Zn	Cr	Ti
253518	0.80	0.00	0.01	0.48	2.52	5.62	0.00	0.05
253517	0.80	0.04	0.06	0.49	2.51	5.60	0.00	0.04
253516	0.78	0.08	0.07	0.48	2.56	5.69	0.00	0.03
253519	0.80	0.08	0.03	0.51	2.46	7.94	0.00	0.03
M577	0.03	0.09	0.07	0.10	3.75	3.98	0.09	0.12
M743	0.01	0.15	0.08	0.01	3.01	5.93	0.00	0.17

All panels post-weld solution heat treated at 860°F and aged 3 hrs at 250°F + 4 hrs at 350°F.

TABLE XIII

CRACK SENSITIVITY OF FILLER METALS ON 7075-TYPE PLATE

Base Metal	Filler+	Inches of Cracking: Standard Test	Inches of Cracking: Disc.(1) Test
253518	Base Metal	14	-
	X5080	18-1/2*	-
	M577	13-1/2*	-
253517	Base Metal	11-1/2	-
	X5080	21-1/2	-
	M577	14	-
253516	Base Metal	8-1/2	-
	X5080	22*	-
	M577	15*	-
	253519	2	-
	M743	0	15
7075	Base Metal	13	-
	X5080	14-1/2*	-
	253519	0	17-1/2
	M743	0	17**
	5556	14*	-
7178	X5080	10*	14*
	253519	0	18
	M743	0	16**
	5556	16-1/2*	17-1/2*

+Compositions are listed in Table XII or Table I

*Cracked in base metal at one or both edges of fillet. Total cracking reported

**Cracked partially in base metal, partially in weld

(1) See Welding Journal 31, No. 10, 448s-456s, 10/52

TABLE XIV

CORROSION TESTS OF 1/8" 7075-T6 AND 7178-T6 DCSP-TIG WELDED WITH X5080

Exposed 12 weeks to 3-1/2% NaCl by Alternate Immersion

Post-Weld Aging	Original Properties TS KSI	YS KSI	% El 2"	Applied Stress (KSI)	Days to Failure Face in Tension	Root in Tension	% Loss of Strength After Exposure* Stressed Face	Stressed Root	Unstressed
					7075				
None	50.3	-	1.0	25.1	OK 84	OK 84	12	9	7
24 hrs at 212°F	56.5	-	0.5	28.3	OK 84	OK 84	16	14	7
1 wk at 212°F	62.8	59.7	1.3	43.3	4	3	100	100	-
- wk at 212°F**	65.1	-	0.5	32.5	4	OK 84	100	27	13
4 hr at 212°F + 8 hr at 315°F	62.2	58.9	0.8	13.0	3	OK 84	100	31	13
8 hr at 212°F + 3 hr at 325°F	67.5	60.0	1.2	33.8	3	OK 84	100	58	8
					7178				
None	56.7	53.2	1.0	28.4	OK 84	OK 84	30	32	44
24 hr at 212°F	64.2	-	0.8	32.1	OK 84	OK 84	39	35	34
1 wk at 212°F	63.3	-	0.5	43.2	1	1	100	100	-
1 wk at 212°F**	71.1	-	0.5	35.5	52	24	100	100	24
4 hr at 212°F + 8 hr at 315°F	64.7	-	1.0	32.3	OK 84	OK 84	42	38	6
8 hr at 212°F + 3 hr at 325°F	71.5	69.0	1.0	35.7	83	OK 84	100	29	11

*Average. 2 specimens
**Note - different stress level

TABLE XV

CORROSION TESTS OF 1/8" 7178-W AND -T6 DCSP-TIG WELDED WITH X5080

Exposed 12 Weeks to 3-1/2" NaCl by Alternate Immersion

Sheet Temper	Post-Weld Aging	Orig. Properties TS KSI	Orig. Properties YS KSI	Orig. Properties % El 2"	Applied Stress KSI	Days to Failure Face In Tension	Days to Failure Root In Tension	% Loss of Strength Stressed Face	% Loss of Strength Stressed Root	% Loss of Strength Unstressed
-T6	6 hr at 225 + 6 hr at 350°F	62.4	61.2	0.5	45	3	77	100	100	43
					30	OK 84	84	42	100	-
					15	OK 84	OK 84	54	58	-
-T6	6 hr at 225 + 8 hr at 350°F	62.6	60.6	0.8	45	2	84	100	100	58
					30	OK 84	84	47	100	-
					15	OK 84	OK 84	22	58	-
-T6	8 hr at 212 + 8 hr at 350°F	60.9	59.2	0.8	45	3	74	100	100	46
					30	77	84	100	100	-
					15	OK 84	OK 84	33	43	-
-T6	8 hr at 212 + 3 hr at 325°F	62.6	-	0.5	45	3	OK 84	100	33	44
					30	OK 84	OK 84	25	15	-
					15	OK 84	OK 84	11	53	-
-W	6 hr at 225 + 8 hr at 350°F	59.7	-	0.5	45	1	83	100	100	80
					30	74	OK 84	100	53	-
					15	OK 84	OK 84	64	40	-

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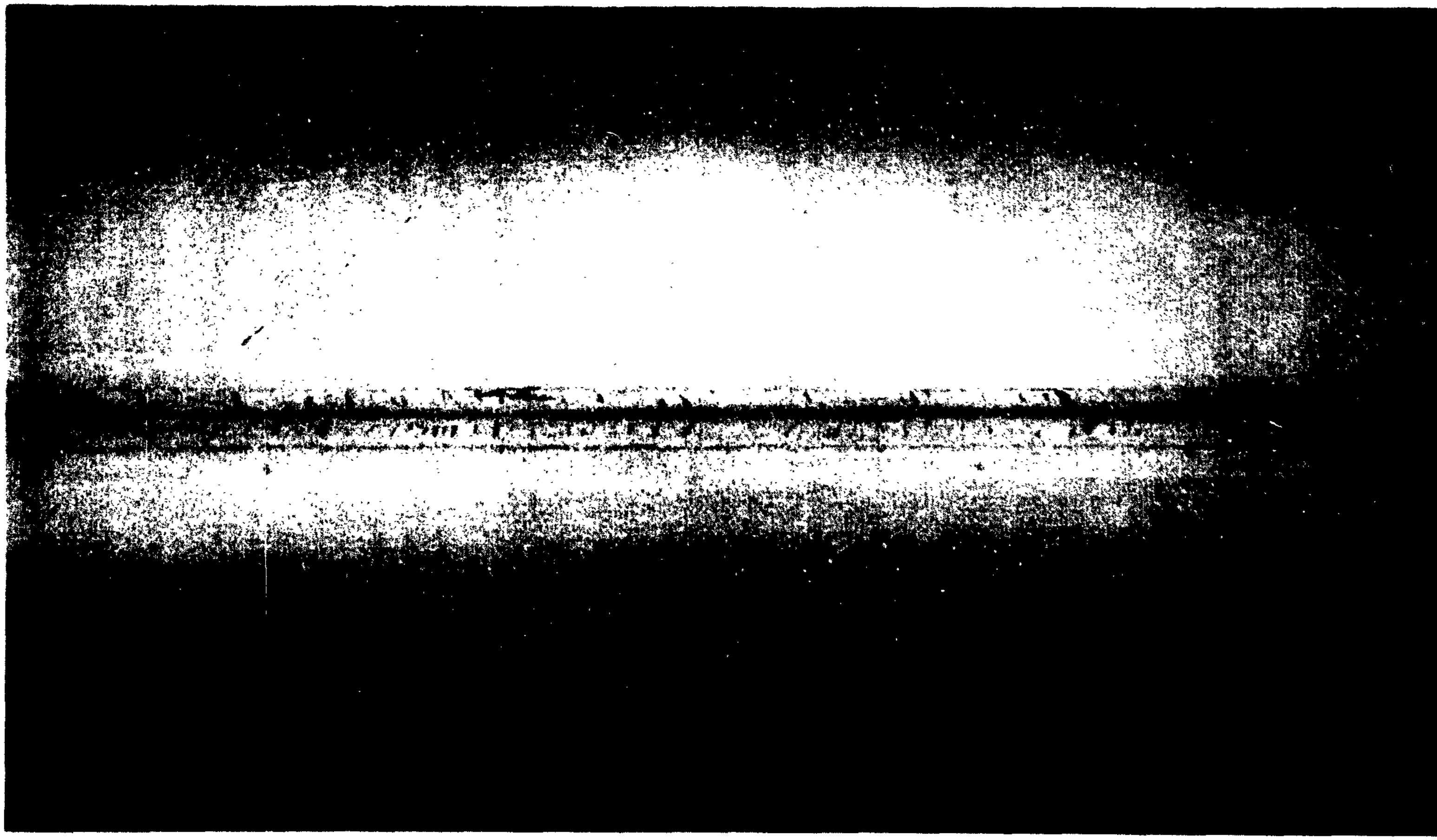
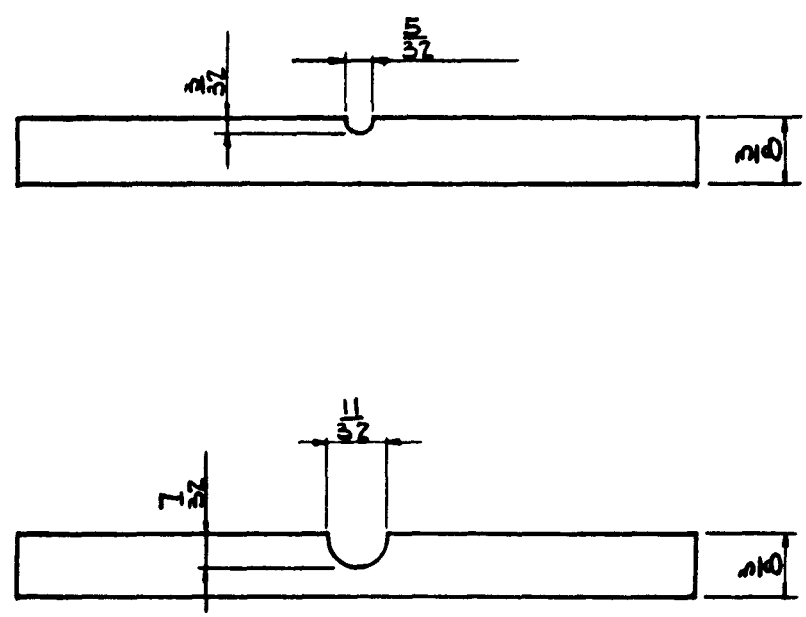


Figure 1

Shows transverse cracks in 1/8-in. 7178 sheet welded at high speed



COPPER WELD BACKING BARS

FIG. 2

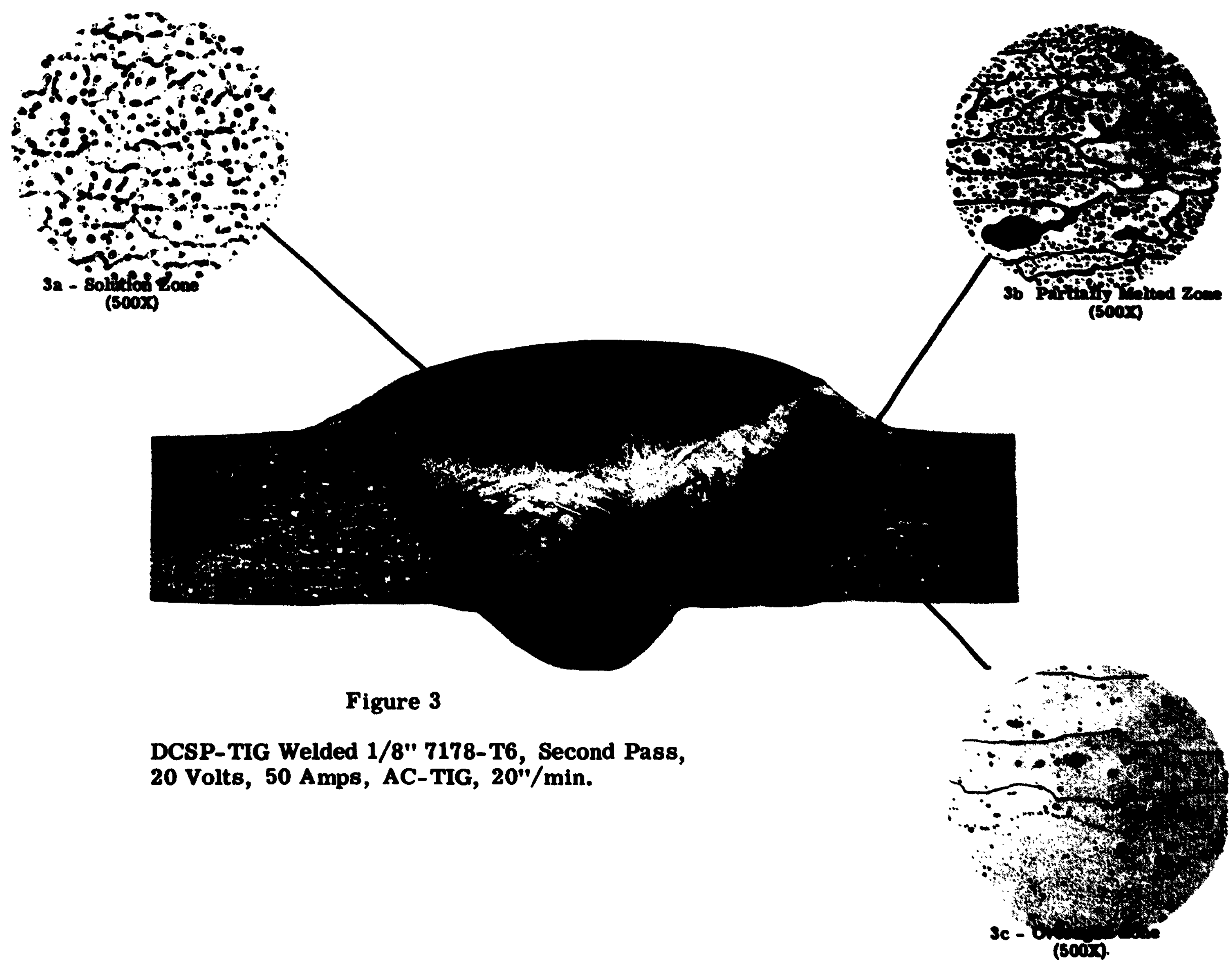


Figure 3

DCSP-TIG Welded 1/8" 7178-T6, Second Pass, 20 Volts, 50 Amps, AC-TIG, 20"/min.

131711AJ
131724AJ
131725AJ
131726AJ

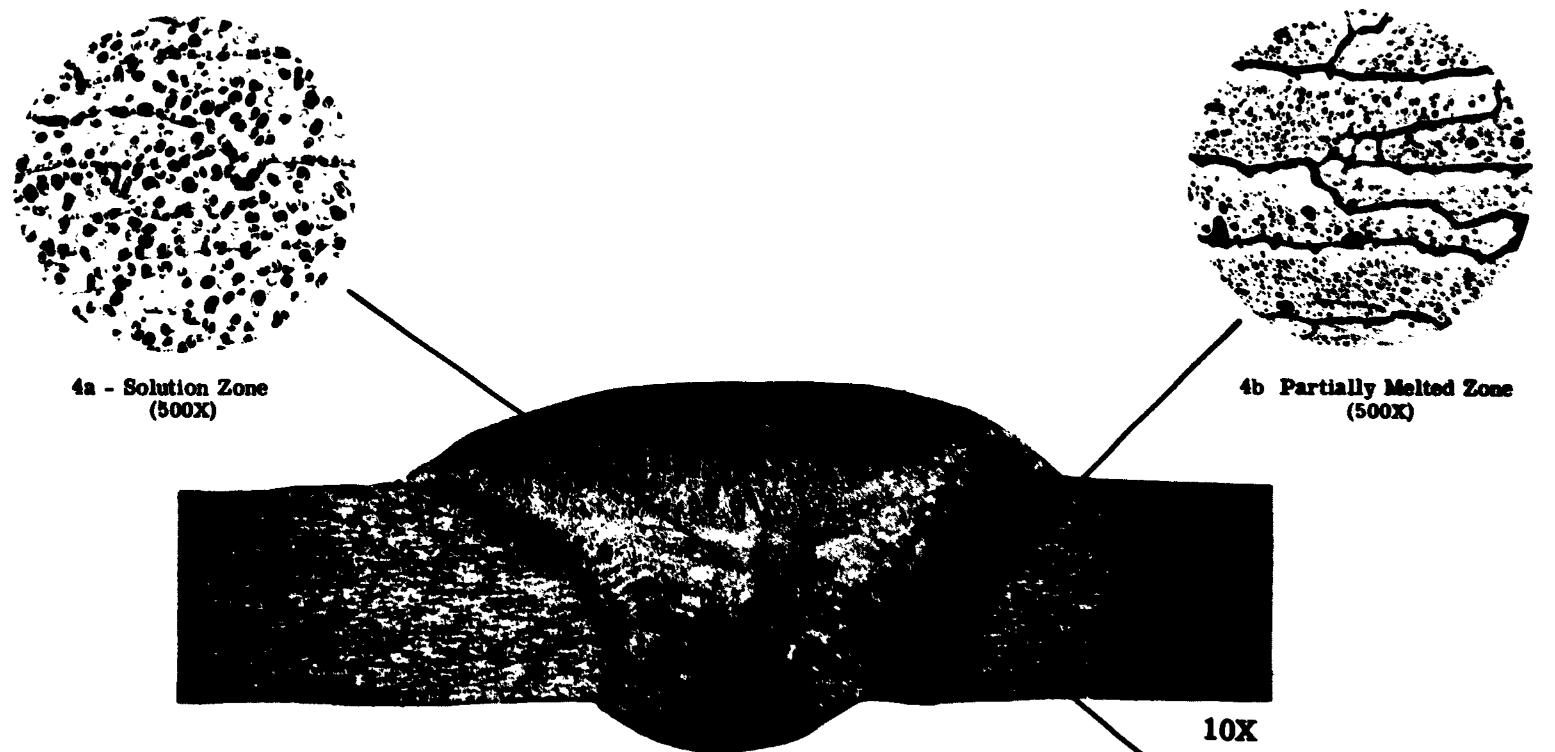


Figure 4

DCSP-TIG Welded 1/8" 7178-T6 Reheated by Second Pass AC-TIG 20 Volts, 20 Amps, 6"/min. Insulated Backing

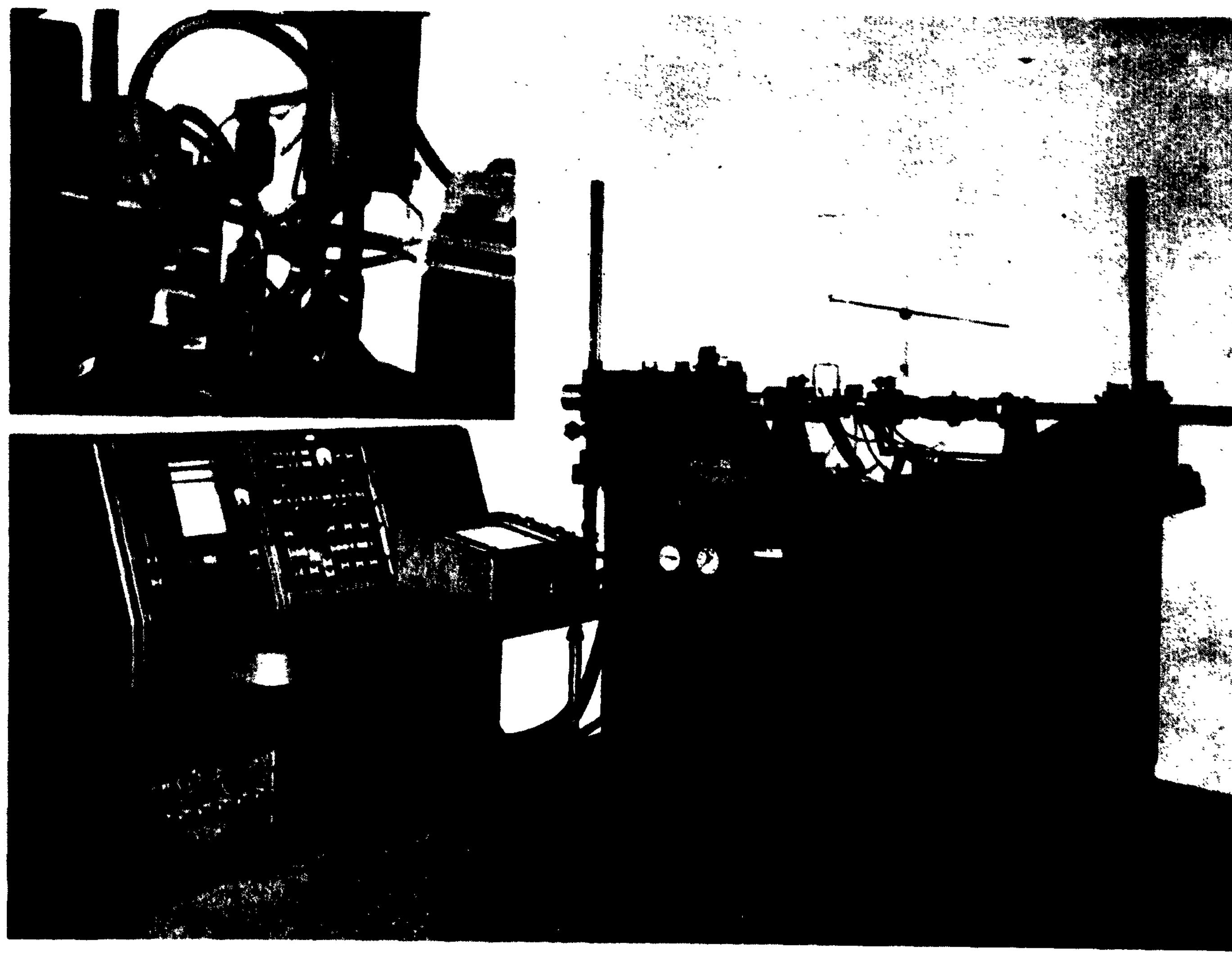


Figure 5

Marquardt Tester

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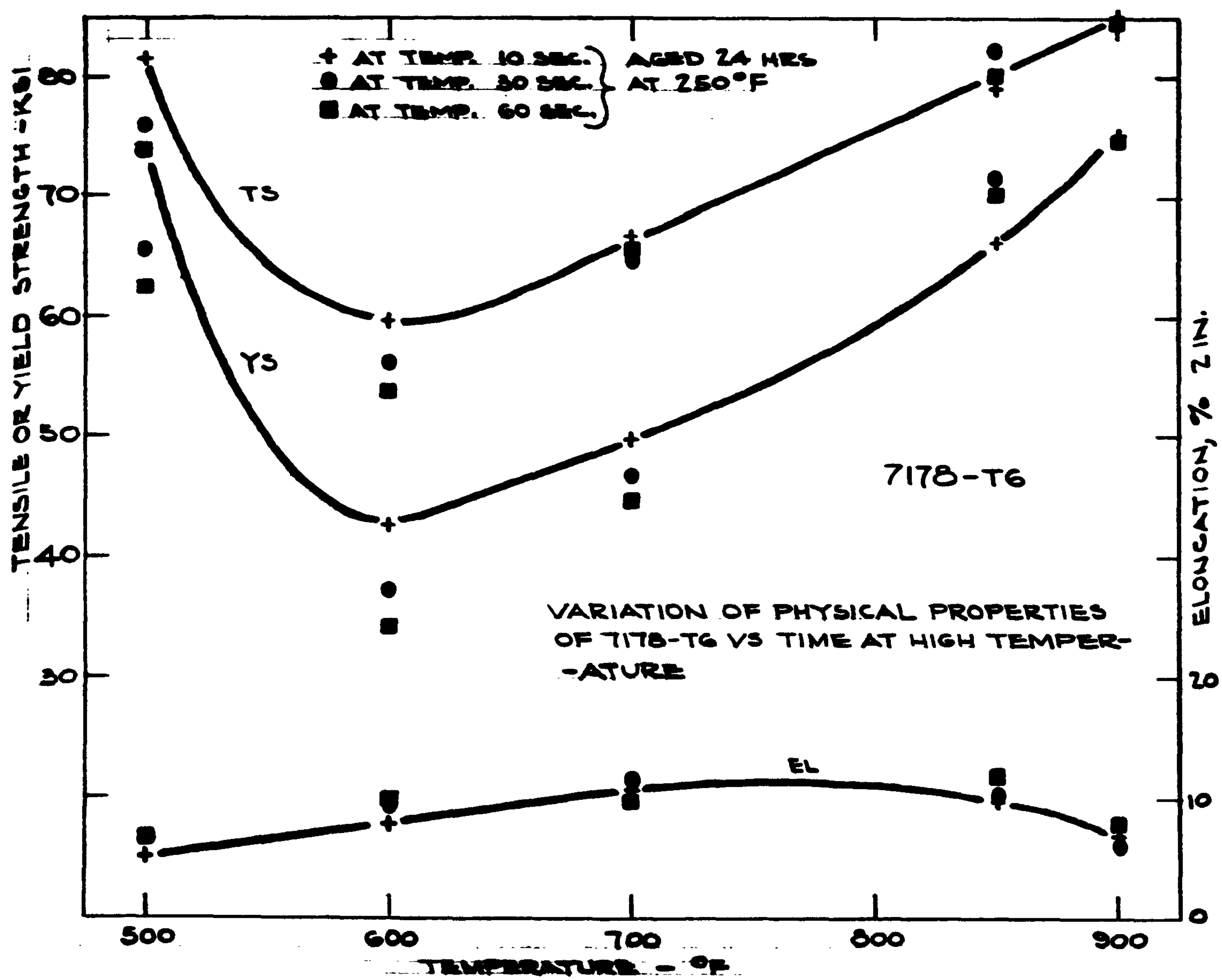


+ AT TEMP. 10 SEC.
● AT TEMP. 30 SEC.
■ AT TEMP. 60 SEC.
AGED 24 HRS AT 250°F
TS
YS
EL
7178-T6
VARIATION OF PHYSICAL PROPERTIES OF 7178-T6 VS TIME AT HIGH TEMPERATURE
TENSILE OR YIELD STRENGTH - KSI
ELONGATION, % 2 IN.
80
70
60
50
40
30
20
10
0
500
600
700
800
900
TEMPERATURE - °F

FIGURE 6

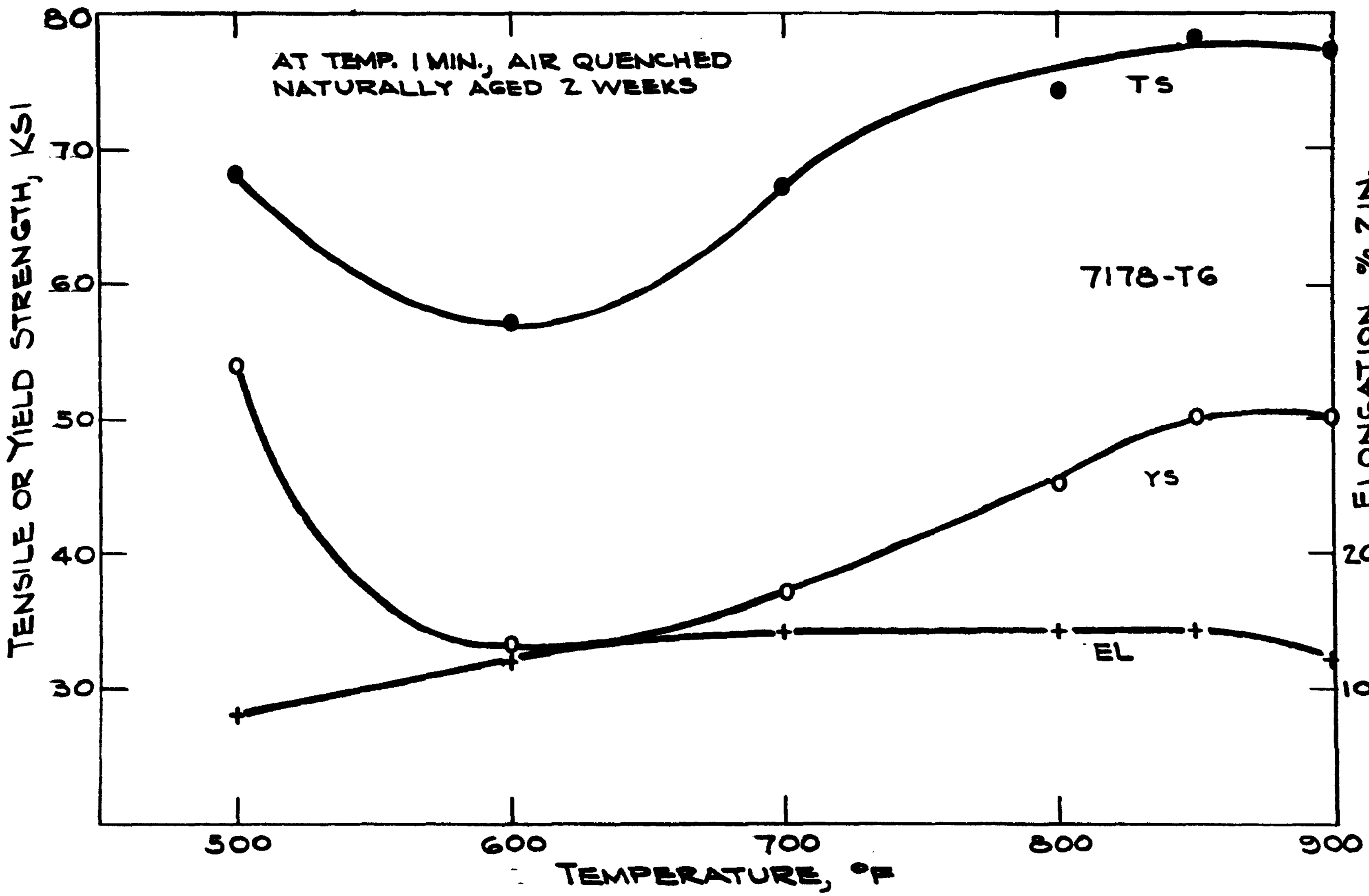


FIG. 7 - VARIATION OF PHYSICAL PROPERTIES OF 7178-T6 VS TIME AT HIGH TEMPERATURE

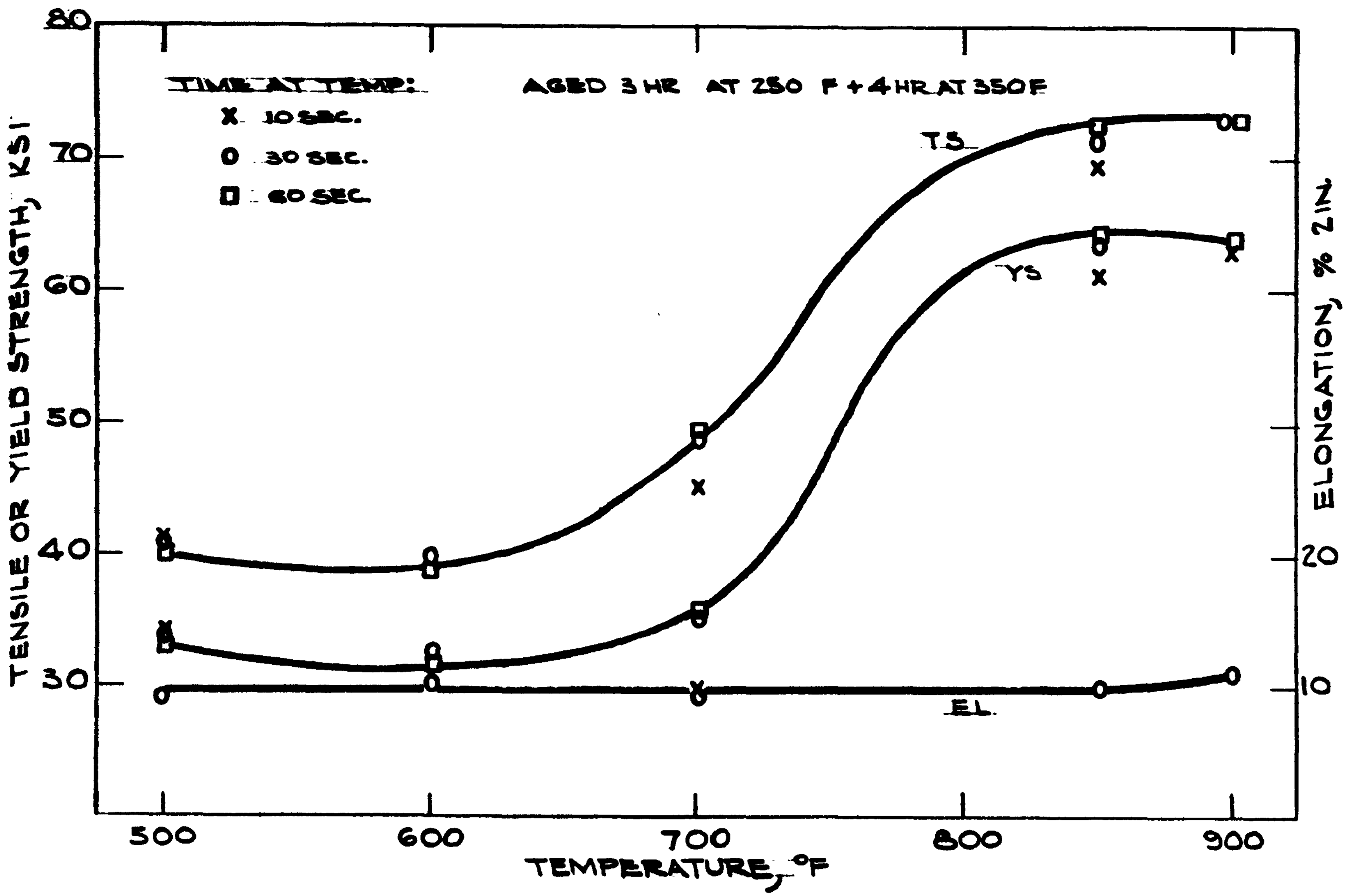


FIG. 8 - ALLOY 253518 5.7 Zn 2.6 Mg 0.8 Cu 0.5 Mn AS-FABRICATED VARIATION OF PHYSICAL PROPERTIES VS TIME AT HIGH TEMPERATURES

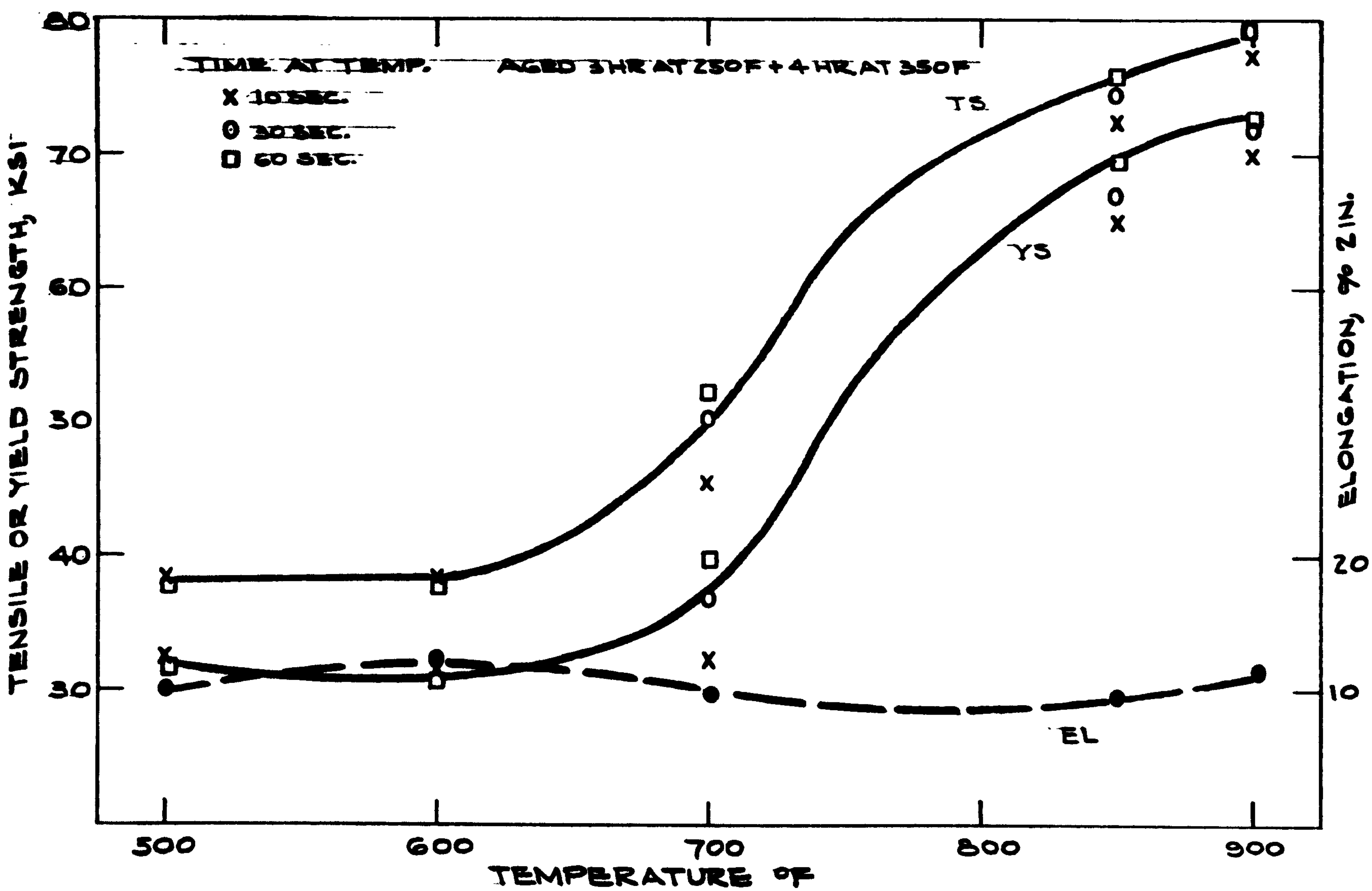


FIG. 9 - ALLOY 253519 7.9 Zn 2.5 Mg 0.5 Mn 0.8 Cu AS FABRICATED
VARIATION OF PHYSICIAL PROPERTIES VS TIME AT HIGH TEMPERATURES

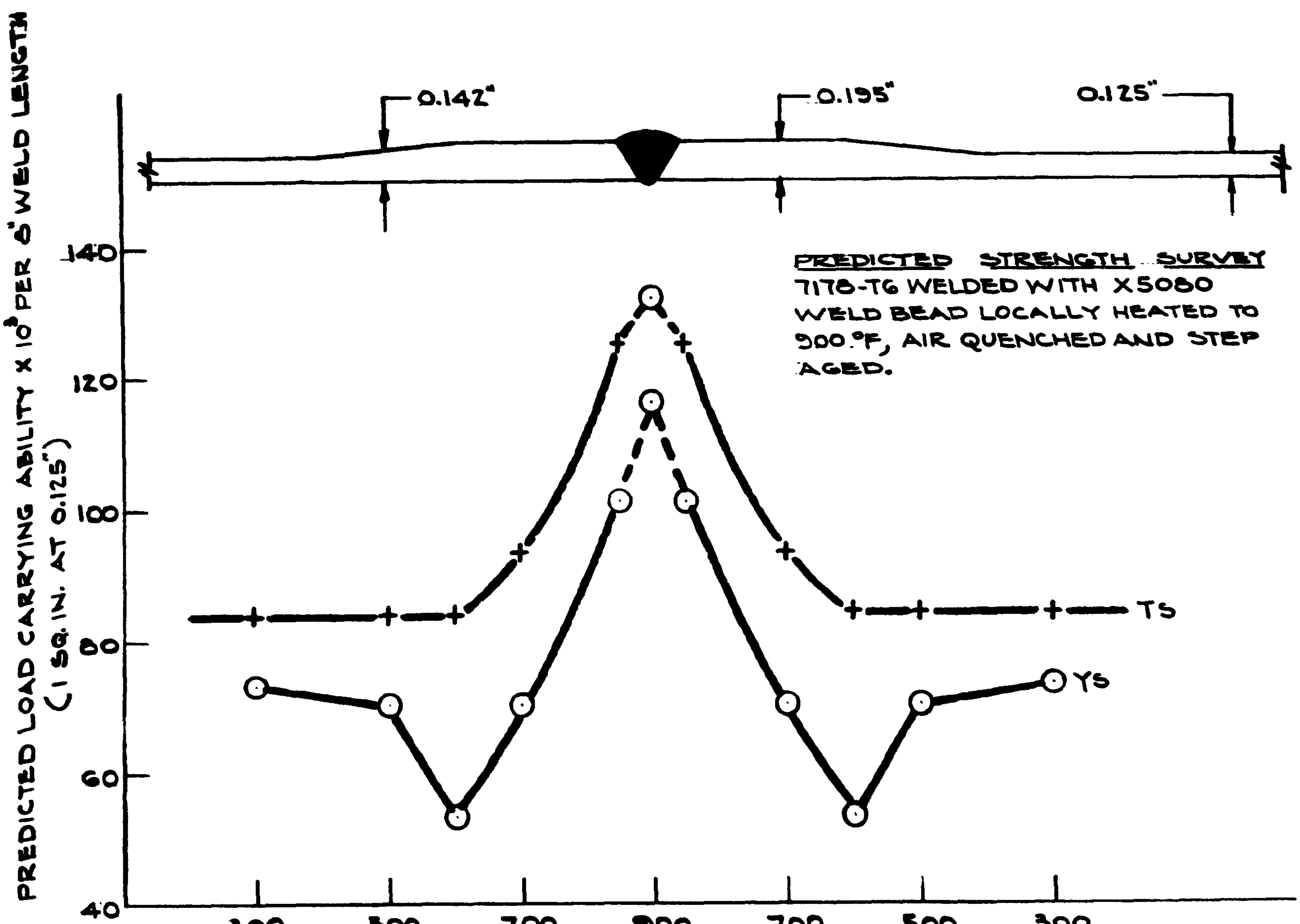


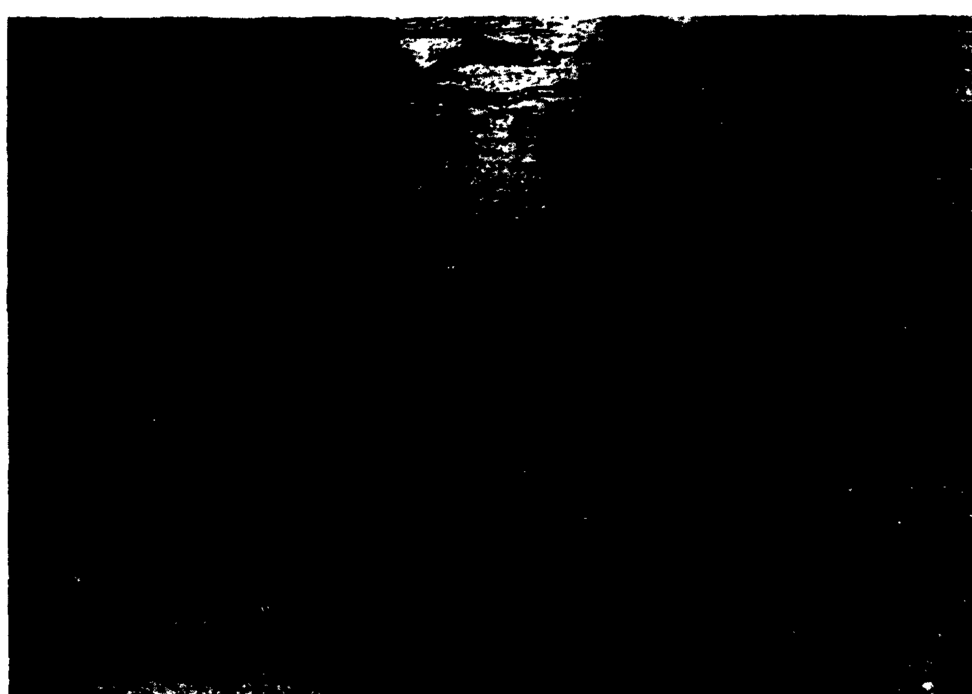
FIG. 10 — TEMPERATURE ACHIEVED DURING LOCAL HEATING-°F

133803AJ

Figure 11 100X

Microprobe Traverse

Automatic Weld, High Purity 7075, 4043 Filler



133804AJ

Figure 12 100X

Microprobe Traverse, Manual Weld

High Purity 7075, 4043 Filler

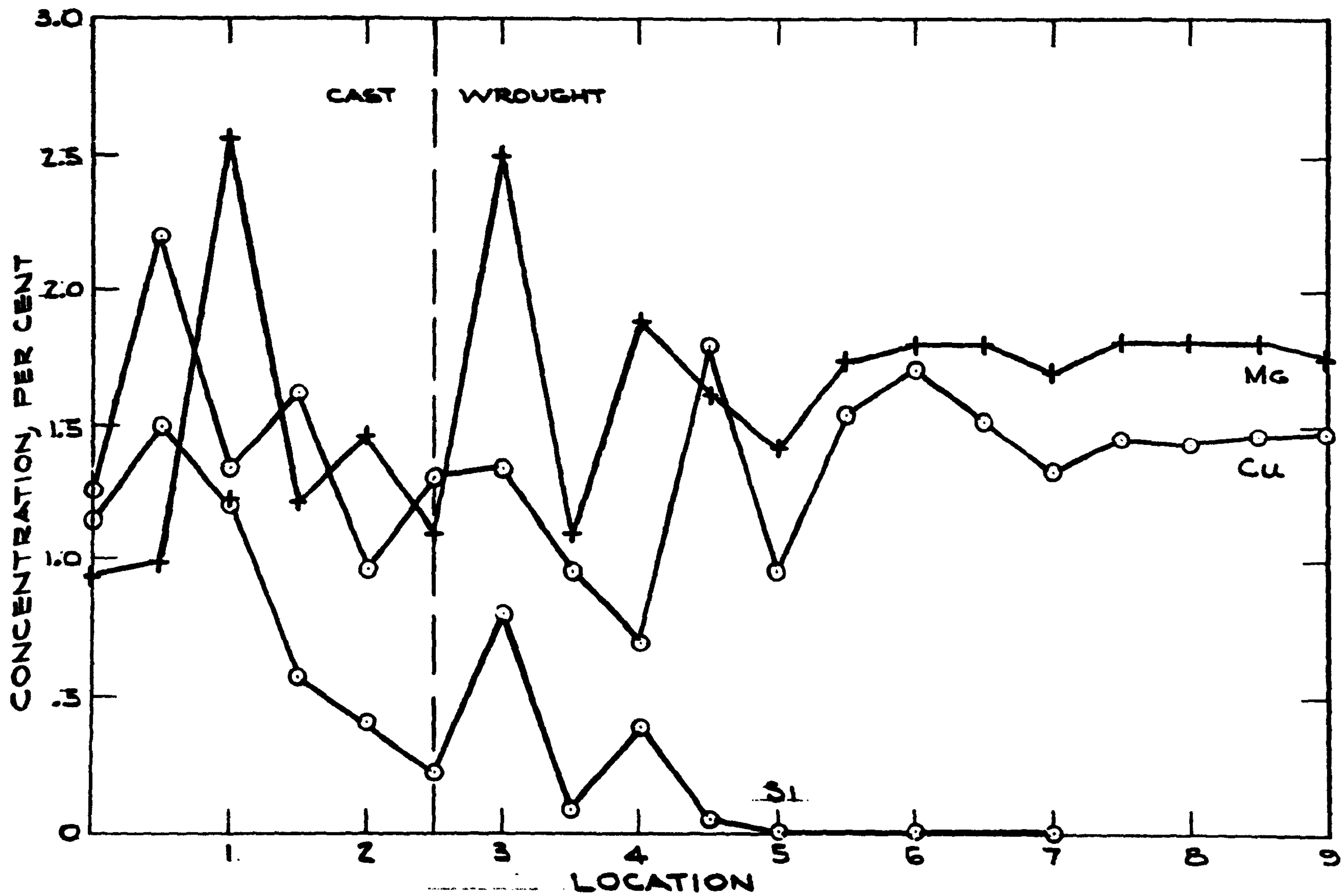


FIG. 13 - MICROPROBE TRAVERSE AUTOMATIC WELD

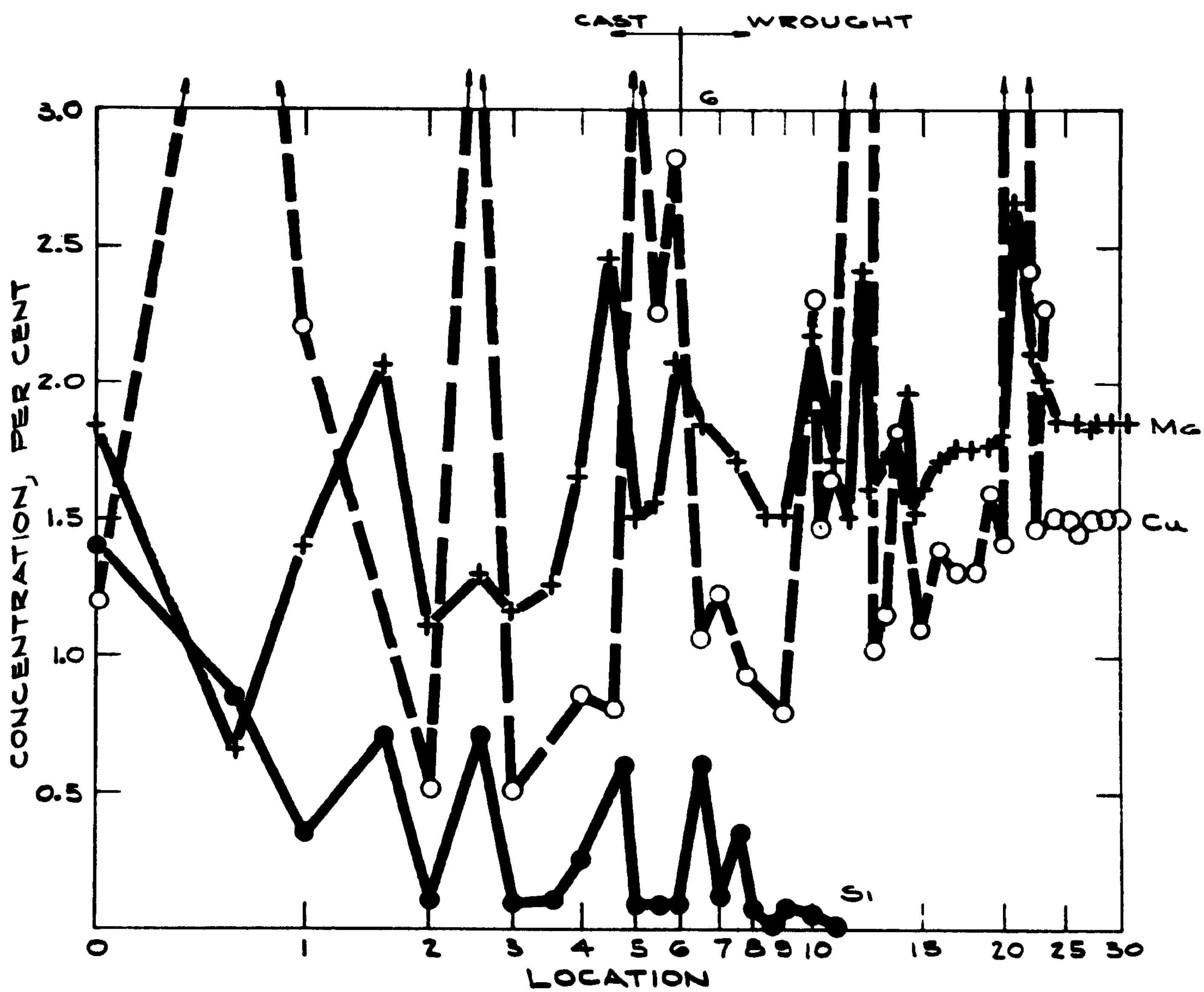


FIG. 14- MICROPROBE TRAVERSE MANUAL WELD

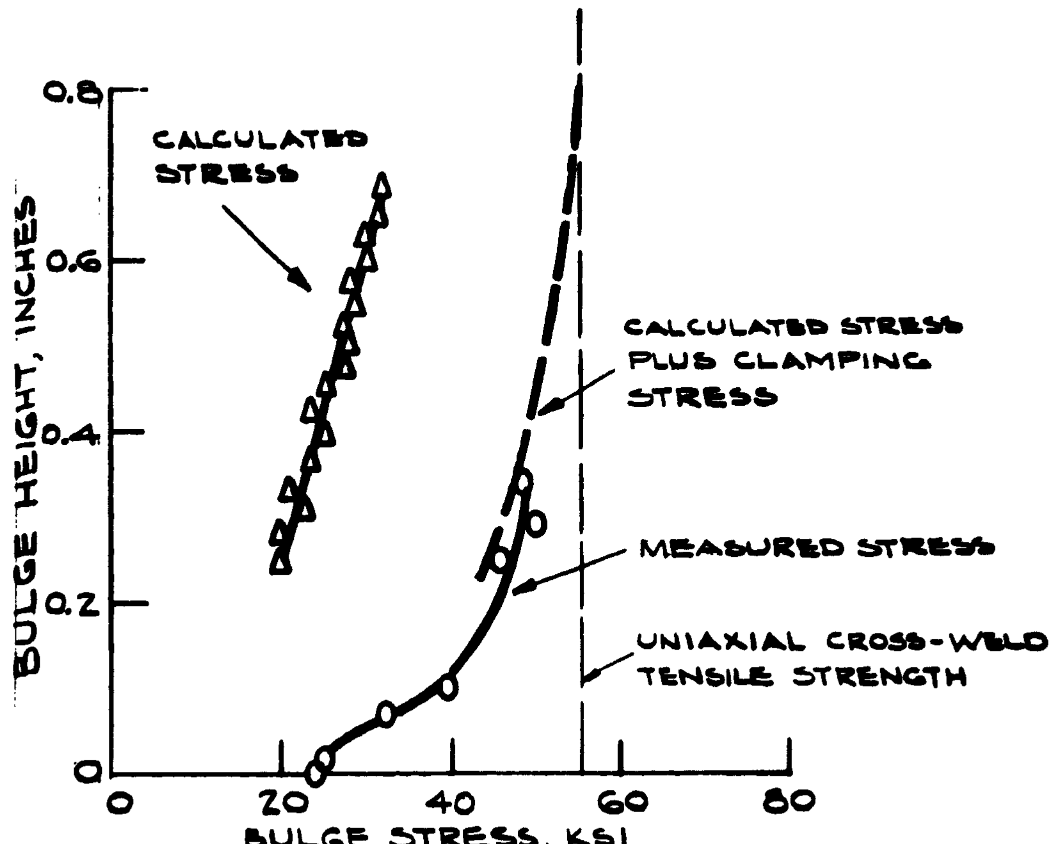


FIG 15 - CALCULATED AND MEASURED STRESSES
BULGE TEST 1/8" 7178-T6, 5556 FILLER
DCSP-TIG WELD

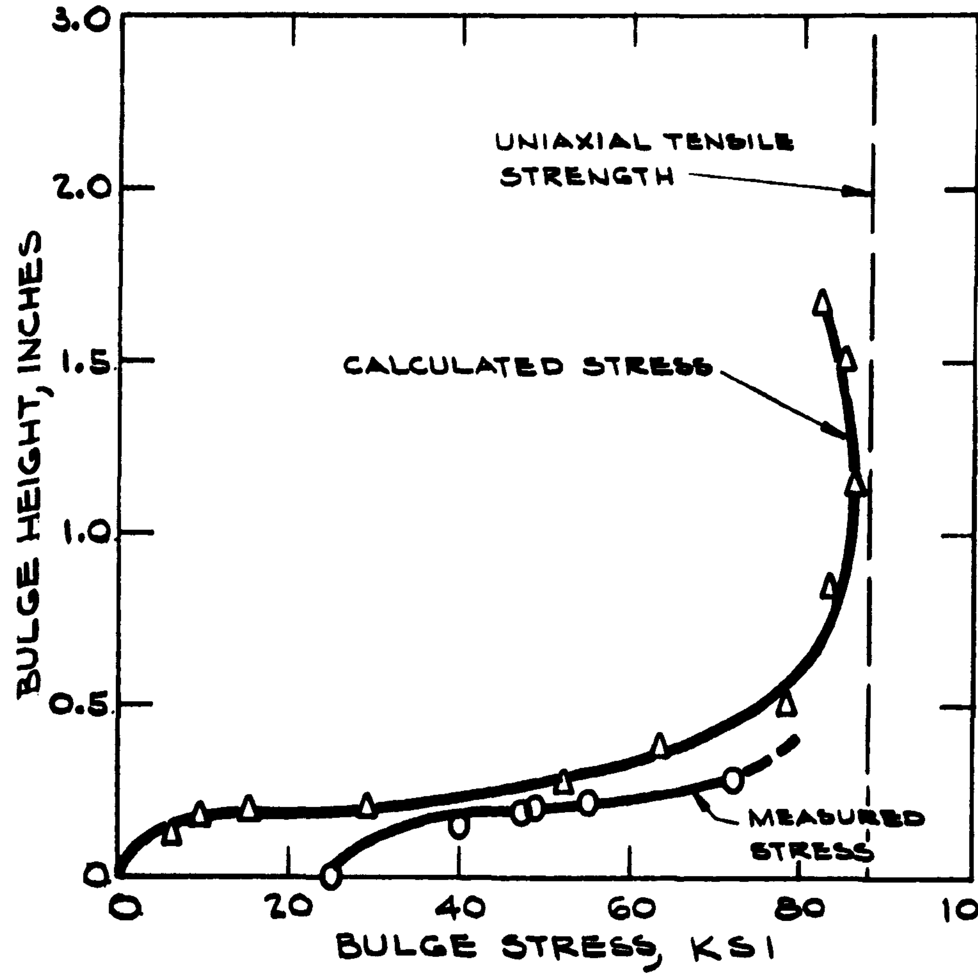


FIG. 16 - CALCULATED AND MEASURED STRESSES BULGE TEST 1/8" 7178-T6 UNWELDED SHEET

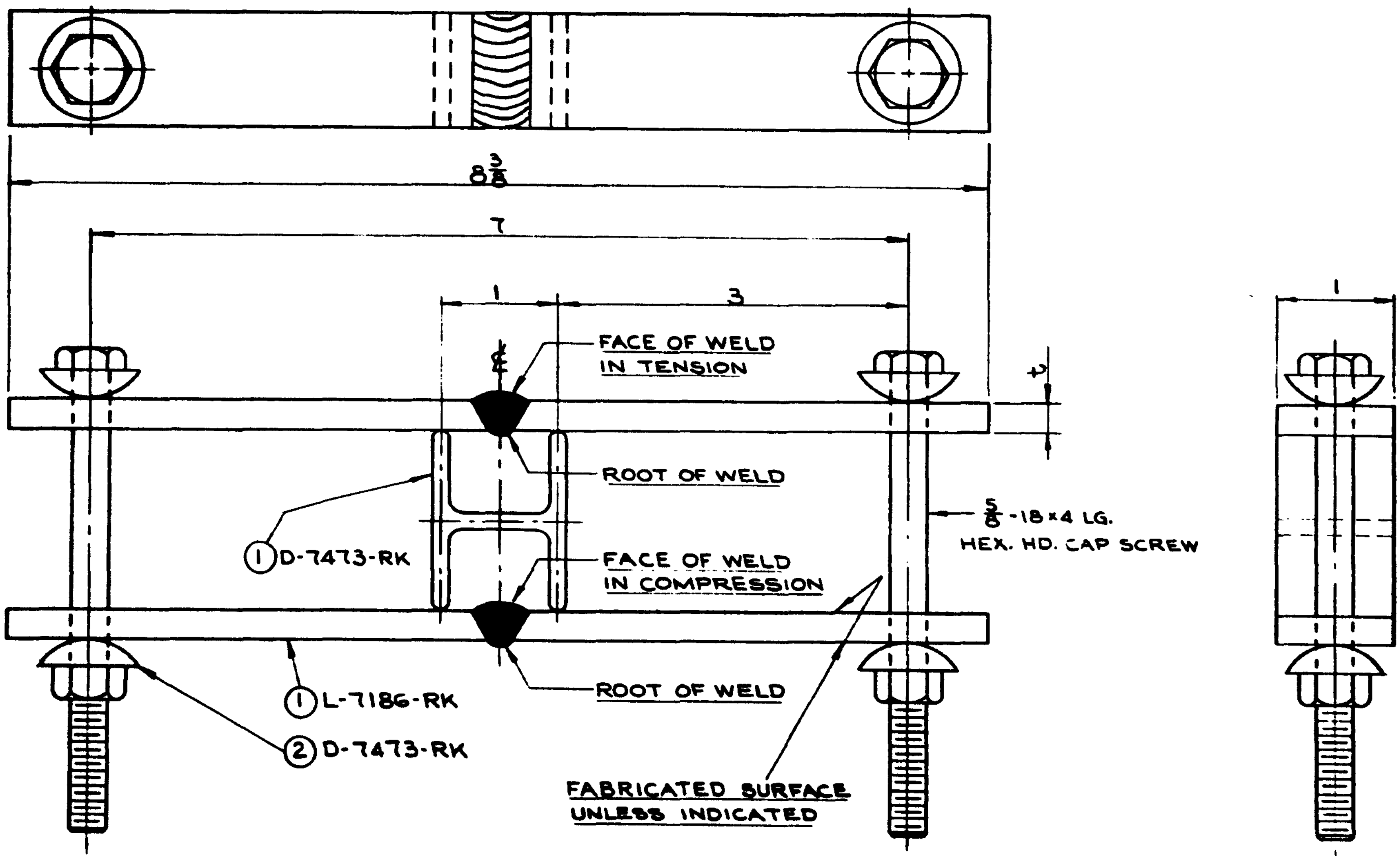


FIG 17 BEAM STRESS CORROSION ASSEMBLY

S-265607 - Post Weld Aged 8 hr at 212°F and 8 hr at 300°F
S-265606 - Post Weld Aged 6 hr at 225°F and 6 hr at 350°F
S-265607 - Post Weld Aged 6 hr at 225°F and 8 hr at 350°F

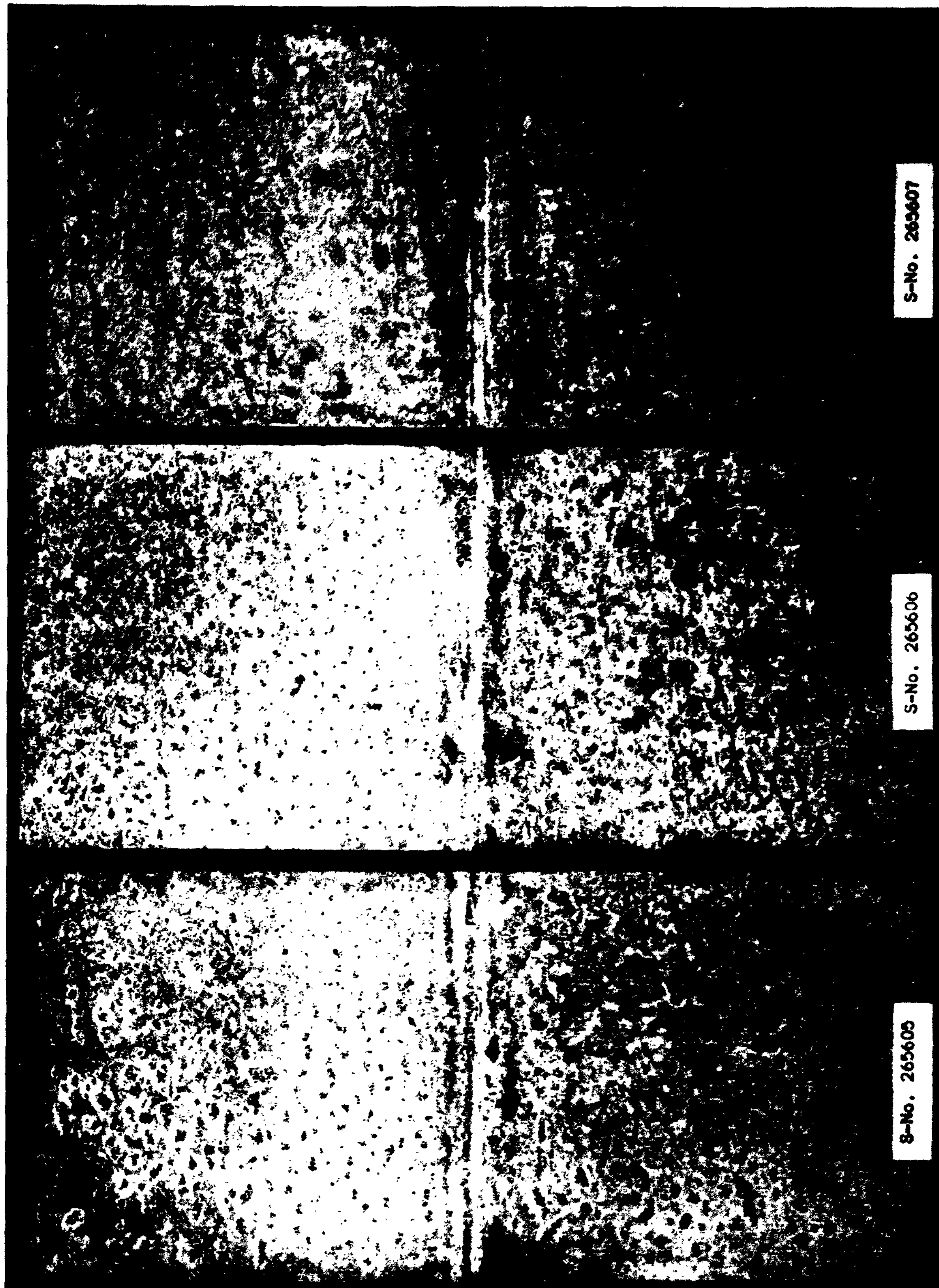


Figure 18

7178-T6 DCSP-TIG Welded, X5080 Filler, 12 Weeks, 3-1/2% NaCl A.I.

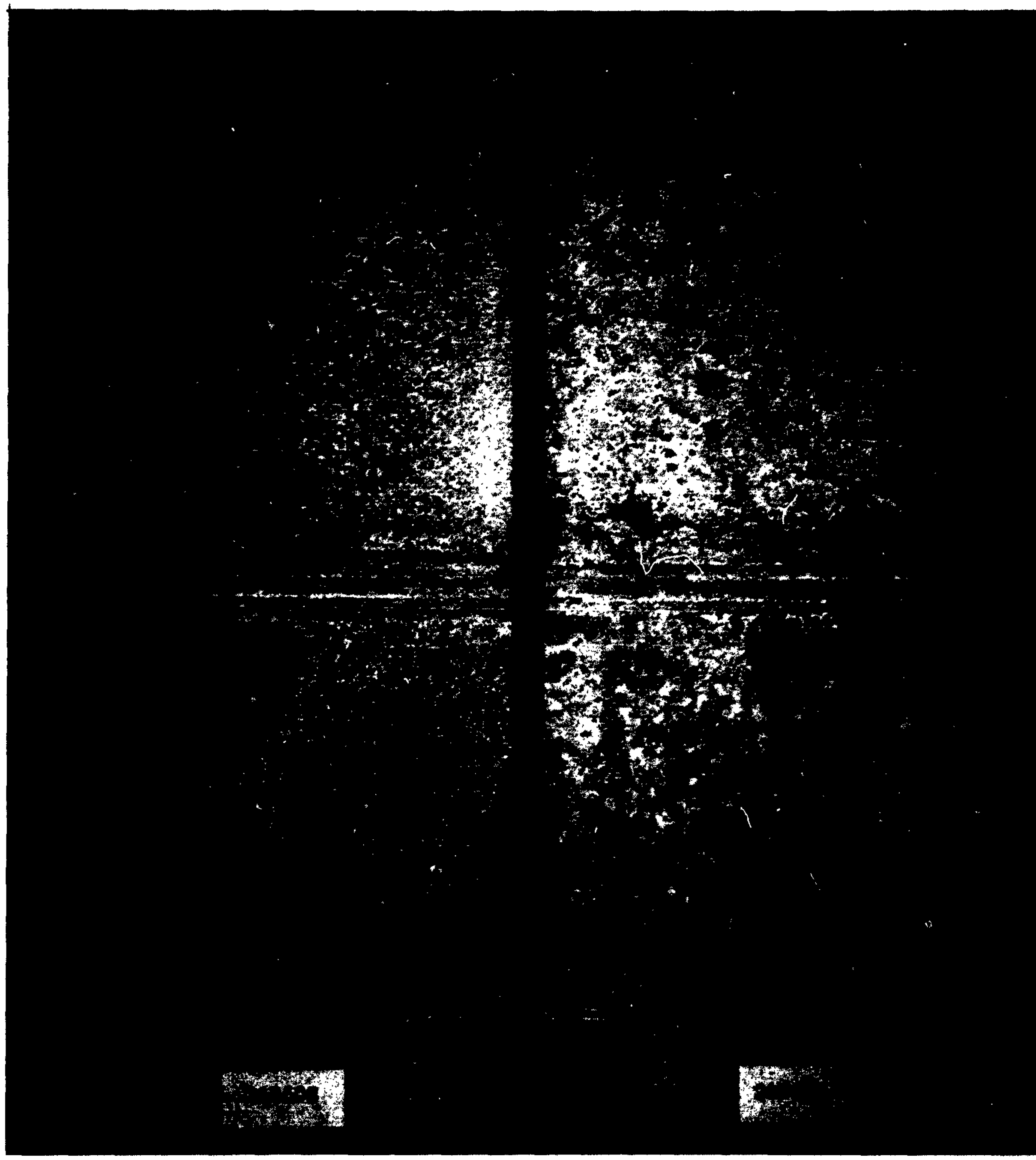


Figure 19

PA1084J

7178-T6 Post Weld Aged
8 hr at 212°F + 3 hr at
325°F

7178-W Post Weld Aged
6 hr at 225°F + 8 hr at
350°F

7178 DCSP-TIG Welded, X5080 Filler

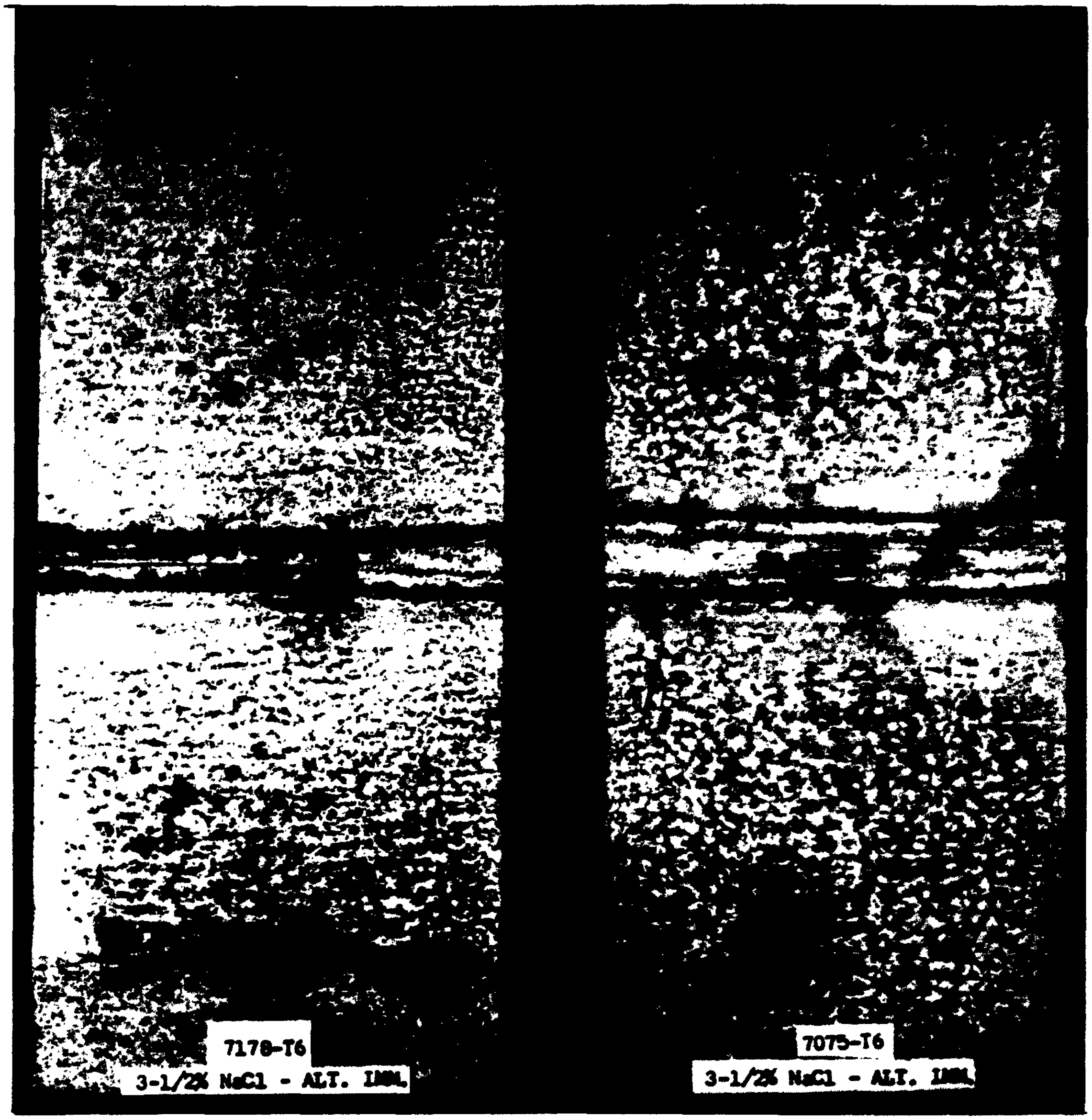


Figure 20

7178 and 7075, DCSP-TIG Welded, 5556 Filler,
12 Weeks, 3-1/2% NaCl A.I.